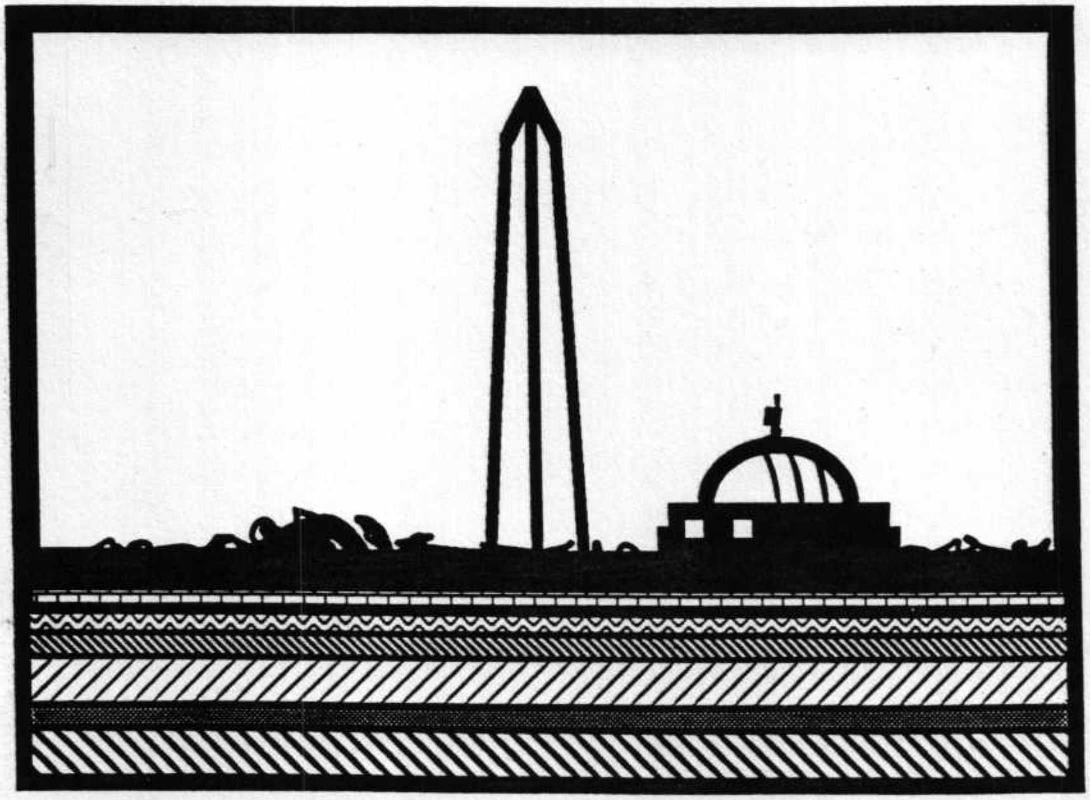
NAGT

EASTERN SECTION

FIELD TRIP GUIDEBOOK
TO THE GEOLOGY OF THE METRO-DC REGION

39 th ANNUAL MEETING APRIL 20-23, 1989



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GENERAL GEOLOGY OF

THE CENTRAL MARYLAND PIEDMONT

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The purpose of this field trip is to examine some of the characteristic petrology and structure of the gneiss "domes" and associated rocks exposed in the Baltimore region. This area was last visited by an Eastern Section NAGT field trip in 1977 under the leadership of the late William Crowley of the Maryland Geological Survey. Since that time, construction and increased problems with parking have made new outcrops available and removed others from easy access. One of the sites used in that trip will be revisited (Stop 8).

The rolling hills, high ridges, and steep sided valleys of the Baltimore area of the Maryland Piedmont owe their existence to a complex set of differing lithologies. While all the rocks are metamorphosed the rock types range from ultramafics and mafics of plutonic and volcanic origin (Baltimore Mafic Complex) to more felsic supracrustal rocks (Ellicott City Granodiorite) to varied metasediments (Glenarm Super Group), and ancient Precambrian gneiss (Baltimore Gneiss).

There are abundant small outcrops of all of these rocks in the area. However, few continuous exposures of contacts have been found. This plus the complex folding and faulting of the region has produced a range of interpretations of the geologic history of the area and its relationship to the rest of the Appalachian orogen. In the past two decades detailed mapping, petrological, and structural analyses have produced broad scale agreement on the general tectonic setting and processes that could have produced this wonderfully diverse terrain. A generalized geologic map of the area is given in Figure 1.

GEOLOGIC SETTING

The oldest rocks in the region are exposed in the center and on the flanks of several high ridges which owe their existence to resistant Precambrian gneiss (Baltimore Gneiss, Stop 1) mantled by a thin layer of quartzites and schists (Setters Formation) at the center of antiformal structures. The overlying, more easily weathered carbonates of the Cockeysville marble produces valleys on the limbs of these structures. The seven of these features found in the Baltimore region were first mapped and described as gneiss domes by Matthews in 1906-07.

The Phoenix Dome (Stop 2) is the northern most of the seven gneiss-cored structures found along a line from just north of Baltimore southwest toward Washington, D.C. All display a deceptively simple anticlinal form on the scale of outcrop mapping. However, detailed structural mapping aided by geophysical studies and petrographic evidence reveal that they are more likely parts of complex folded nappe structures (Muller and Chapin, 1984; Lang, 1987).

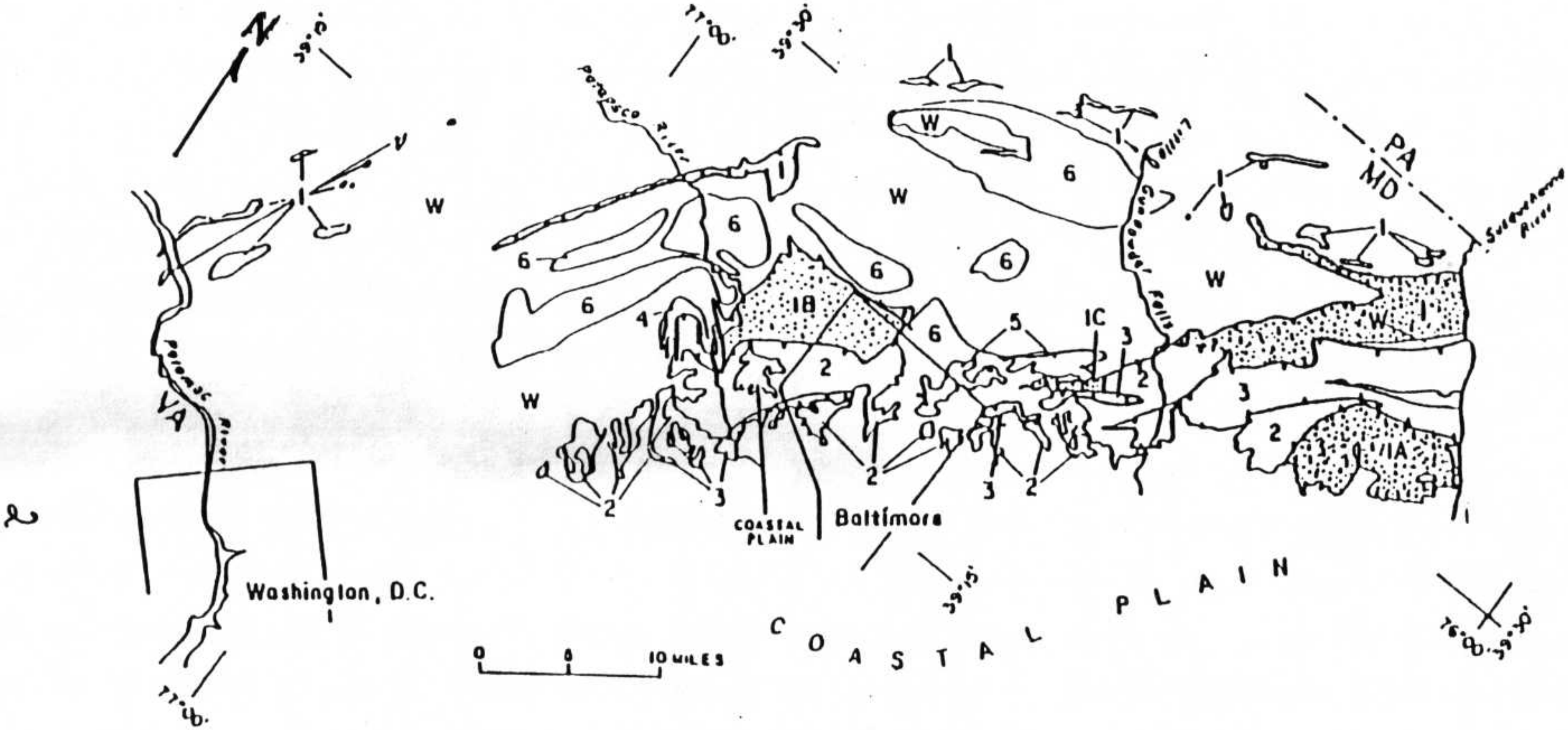


FIGURE 1. Generalized Geologic Map of the Maryland Piedmont (form Sinha, 1988)

1A, 1B, 1C	=	Baltimore Mafic Complex (Ultramafic lenses = 1)	Stops this trip:
2, 3	=	James Run Volcanic and Port Deposit Gneiss	A = Stop 1
4	=	Ellicott City Granodiorite	. .
5	=	Gunpowder Granite	. .
6	=	Baltimore Gneiss Domes	. .

Overlying the Setters and Cockeysville is a heterogeneous sequence of metasediments including a lower mica schist (Loch Raven Schist, Stop 3) and an upper sequence consisting of diamictite (Sykesville Formation, Stop 9), metagraywackes (Morgan Run and Peters Creek Formations), and a laminated quartz schist (Pleasant Grove Formation). All, or some, of these have in the past been variously identified as part of the Wissahickon Formation (Hopson, 1964) or Wissahickon Group (Crowley, 1976) and with the Setters, Cockeysville, and Loch Raven Formations comprise the Glen Arm Super Group of Crowley (1976). A generalized stratigraphic column is provided in Figure 2.

Intercalated with the Wissahickon Group south and east of the Gneiss Domes are allochthonous blocks of ultra mafic to mafic and felsic rocks which Crowley (1976) named the Baltimore Mafic Complex (Stops 6 & 8). The complex includes all rocks originally designated as the Baltimore Gabbro (Hopson, 1964), the metavolcanic James Run Formation (Higgins, 1972), and the Port Deposit, Relay Quartz, and Carrol Gneisses (Crowley, 1976). Crowley (1976) and Morgan (1977) interpreted the complex to represent dismembered and deformed oophiolite/island arc terrane. Recent work by Hanan and Sinha (in press) shows continental contamination of the parent magma prior to crystallization. This plus the association of metagabbros with metavolcanics leads these authors to suggest formation of this complex in a basin on the continent side of a volcanic arc or as a sub-arc pluton, i.e. a continental margin back-arc basin.

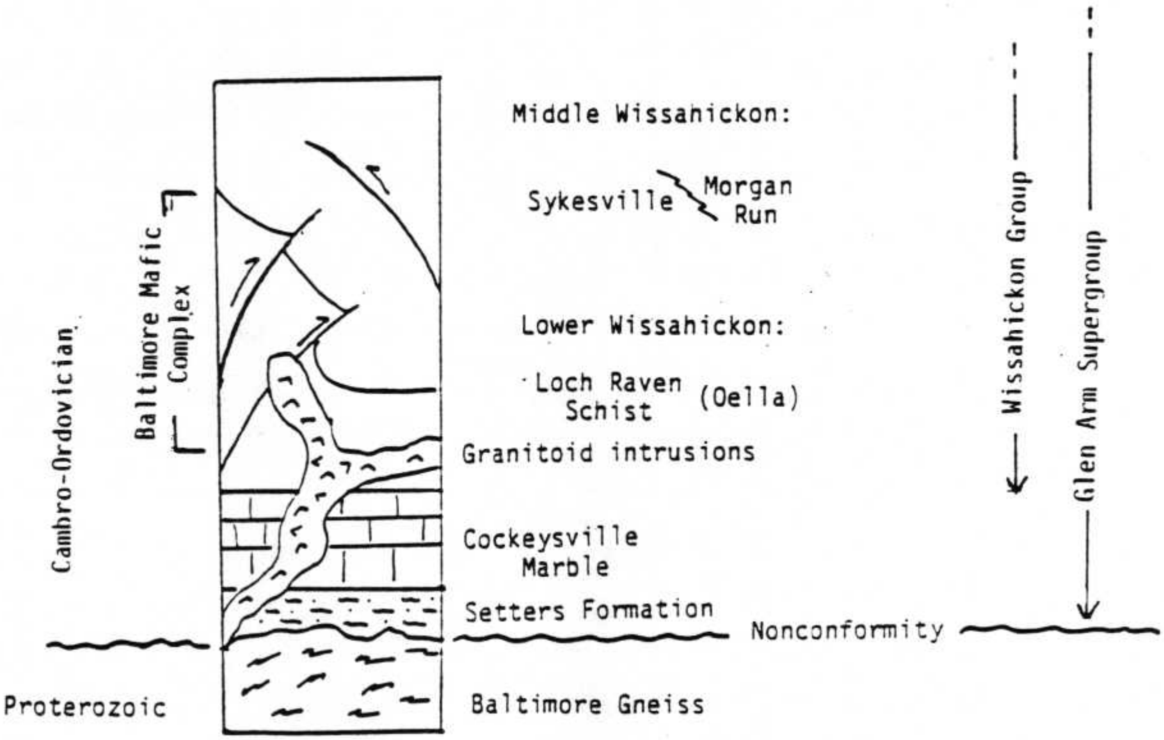
Scattered throughout the Piedmont terranes in the central and southern Appalachians are middle to late Ordovician granitoid intrusives. One of the largest representatives of these in this area is the Ellicott City Granodiorite (Stop 7). Mineral assemblages that indicate a deep level of emplacement have been identified suggesting that thrust stacking associated with the Taconic orogeny induced local partial melting to produce these magmas (Sinha, 1988).

Baltimore Gneiss

The Baltimore Gneiss is a typical metamorphic gneissic rock with clearly defined compositional banding. Most of the Baltimore Gneiss exposed in this region is of fairly homogeneous granodiorite to granitic composition. This differentiation in composition is based on the type of feldspar present. Granitic types contain orthoclase, while the granodioritic type contain more plagioclase. Detailed mapping by Crowley (1976) resulted in the recognition of four distinct subdivisions which were accorded member status. Of these the most common is a layered gneiss with dark and light bands produced by interlayering of biotite rich layers with lighter bands of biotite-quartz-feldspar (oligoclase and microcline). Grain size, ratio of biotite to quartz and feldspar, and scale of layering vary widely. The fabric varies from weakly foliated to strongly layered, migmatic, and locally mylonitic. Granitic dikes and sills are common.

Hopson (1964) employed the model of Finland gneiss domes described by Eskola to interpret the Baltimore domes as a result of diapirs of remobilized basement materials. Subsequent studies have led to the reinterpretation of the gneiss as originating from Grenville age metamorphism of clastic and volcaniclastic sediments that were subsequently multiply deformed through the Paleozoic. Two major thermal events are revealed by U/Pb age determinations (Tilton et al., 1970; Grauert, 1973): one ranging from 1,000 to 1,200

FIGURE 2. Generalized Stratigraphic Column
(modified from Muller and Chapin, 1984)



m.y.b.p. and the other from 420 to 450 m.y.b.p. The detrital appearance of some of the zircons in the gneiss suggests that the primary depositional age is greater than 1,200 m.y. (Tilton, et al., 1970). Muller and Chapin (1984) identified two major periods of deformation in addition to the earlier Grenville event. Three fold generations and planar structures of ductile deformation were attributed to amphibolite facies metamorphism of Taconic-Acadian tectonism (500-360 m.y.). A final, nonpervasive, deformation characterized by open folds and brittle faults in the gneiss were attributed to Alleghanian-Palisades tectonism (260-190 m.y.). When the proposed ages for these events are compared with dates of thermal events based on research in the Baltimore Mafic Complex we find some generalized agreement. Hanan and Sinha (in press) report literature in support of three major thermal pulses somewhat in accordance with the Taconic-Acadian period of deformation noted above:

1. Cambrian (520-490 m.y.) volcanism and plutonism that produced the Baltimore Mafic Complex.
2. Late Ordovician (460-440 m.y.) plutonism and metamorphism.
3. Carboniferous (330-300 m.y.) metamorphism.

Glen Arm Super Group

Fisher, et al. (1979) interpreted the Setters, Cockeysville, Loch Raven (lower Wissahickon) sequence as a record of the development of a passive margin with terrigenous clastics (Setters Formation) derived from a craton to the northwest and deposited in a fluvial and/or coastal environment. However, no sedimentary structures survive on which to base inferences of direction of transport or depositional environment. The Cockeysville marble most likely represents the development of a shallow water carbonate bank. The age of these sediments is problematic. On the basis of lithology and fossil evidence in similar carbonates in the Piedmont in the Chester Valley in Pennsylvania, Fisher (1988) suggests that these are correlative with the Ordovician carbonates found in the Western Blue Ridge province. Alterman (1987) reported finding some Ordovician-like fossils in a single boulder of the Cockeysville at a construction site providing the only fossil support for this presumed age.

The Loch Raven Schist may signal the beginning of deepening water associated with subsidence in a developing compressional tectonic regime (Fisher, 1988) followed by the deposition of a submarine flysch sequence. However, Rogers (1970) suggested that the patchy occurrence of marble, amphibolite, and micaceous quartzite of the lower Wissahickon (Rush Brook Member of the Loch Raven, Crowley, 1976) represents thrusting of the entire Wissahickon Group over the Cockeysville. Fisher (1988) supports this idea and suggests that the Loch Raven (Lower Wissahickon) may be an off-shore equivalent of the Setters Formation. The three lithologies of the flysch sequence are thought to represent three or more stacked thrust sheets (Drake and Morgan, 1981; Muller et al., 1989) with the Morgan Run representing an accretionary wedge developed in front of a westward-moving arc (Baltimore Mafic Complex). The Sykesville, which contains clasts of Baltimore Mafic Complex and Morgan Run, is interpreted by these authors as a melange developed along a subduction zone dipping beneath the arc. Muller, et al. (1989) concluded that the arc, accretionary wedge, and melange were imbricated and thrust onto continental crust during the later stages of the Taconic orogeny. Fisher (1988), however,

argues that the textures in the rocks and their geochemical composition does not support assembly of a sequence of unrelated, widely separated rock units but rather the local telescoping of the elements of a single flysch sequence.

The age of the Wissahickon Group can only be estimated by the brackets provided by rocks of igneous origin. The Sykesville must be younger than the 520 my old volcanic clasts it contains (Fisher, 1988) and the Loch Raven and Morgan Run formations must be older than the 469 my old granite dikes which intrude them (Muth, et al., 1979). If the Sykesville and the Morgan Run are not facies equivalents these limits may be broader (Fisher, 1988).

Baltimore Mafic Complex

The Baltimore Mafic Complex (BMC) consists of metamorphosed plutonic, volcanic, and supracrustal rocks of mostly mafic composition with a few associated units of ultramafic and felsic materials. Originally these rocks were interpreted as intrusives into the Wissahickon. It is now recognized that the BMC has been tectonically emplaced (Hopson,1964; Southwick,1970). The BMC occurs in three large tectonic blocks containing mappable stratigraphy identified by Hanan and Sinha (in press), as isolated lenses and pods in the Wissahickon (Crowley, 1976), and in two thrust slices (Fisher, 1979) of metavolcanic rocks (James Run Formation of Higgins, 1972). The generalized igneous stratigraphy identified mostly from the Susquehannna Block by Hanan and Sinha (in press) consists of a basal serpentine unit overlain by a metagabbro with upper level layers of peridotite. Amphibolites, primarily in the Gunpowder block are considered by these authors to be derived from gabbro and peridotite. Two distinct events are suggested for this derivation. Magnesium-rich hornblende is found surrounding pyroxenes and probably represents late-magmatic crystallization due to fluid enrichment of the residual liquid. The tremolite-actinolite represents later hydrous recrystallization that may be related to Ordovician metamorphism.

Among the compositional and isotopic evidence used by Hanan and Sinha (in press) to argue for a continental association for the origin of these rocks are recent U/Pb zircon dates that indicate an approximate 500 m.y. crystallization age of the complex and provide evidence of an inherited Grenville (1.1 b.y.) component. According to these authors the BMC formed in an ensialic back-arc basin west of the James Run volcanic arc from parent magma from a depleted mantle source and contaminated by hydrous aluminous sediment. Low K abundance requires that the Baltimore Gneiss be excluded from the contamination process suggesting that during crustal thinning of back-arc basin formation depleted mantle rose and became contaminated by interaction with low K sediments derived from the rifted continental lithosphere containing reworked components of Baltimore Gneiss in the form of heavy minerals (zircon).

ROAD LOG

Mileage

00.0 Leave Holiday Inn, Silver Spring
North on Georgia Ave. to Capital Beltway (I 495)

1.4 Enter Capital Beltway East

6.2 Exit 27 to I 95 North (to Baltimore)
Sykesville formation outcrops at the base of the interchange. The entire route of I 95 until we get into the city of Baltimore is in the Coastal Plain Province. Hills on either side are underlain by Cretaceous sediments.

10.6 Sand and gravel pits in this area are in the Patuxent Formation. None are currently operating.

16.1 Rocky Gorge Dam. Patuxent River

27.6 Cross Patapsco River

29.2 Baltimore Beltway (I 695) interchange
Continue on I 95 North to Fort McHenry tunnel.

View of Baltimore Harbor area and downtown Baltimore (far left).

36.7 Fort McHenry Tunnel Toll Area

39.1 Leave expressway at Exit 60 Moravia Rd.
Northwest on Moravia Rd., pass form Coastal Plain into the Piedmont Province between the intersection with Bel Air Rd and Harford Rd. Across Harford Rd. Moravia becomes Cold Spring Lane. Continue on Cold Spring to the campus of Morgan State University.

43.9 Cross bridge over Herring Run
Turn left onto campus service road. First right to parking area for the Washington Center service building. Disembark and walk back toward Cold Spring Lane and follow path down to stream just before bridge.

STOP 1 Morgan State University – Baltimore Gneiss

(Adapted from Muller and Chapin, 1984)

Four basic lithologies comprise the Baltimore gneiss (Crowley, 1976). These are, in order of abundance: layered gneiss, augen gneiss, streaked augen gneiss, and hornblende gneiss and amphibolite. Minor amounts of biotite schist are also present. In addition, sheetlike bodies of granitic leucogneiss, probably representing Precambrian intrusive rocks, occur in several of the gneiss anticlines.

At this stop, the dominant lithology is a medium-grained, uniform to weakly foliated, quartzofeldapathic gneiss layered on a scale of a fraction of an inch to several feet thick. The rock is composed of subequal amounts of quartz, oligoclase, and microcline with biotite as the principal mafic mineral (Hopson, 1964; Crowley, 1976). Sphene, epidote, allanite, apatite, magnetite, and zircon comprise the accessory and trace minerals. Muscovite is present only in augen gneisses where they have been sheared and mylonitized. Intercalated with the layers of quartzofeldspathic gneiss are more mafic gneisses and amphibolite. The mineralogy of these is more variable and ranges from plagioclase-quartz-biotite with minor garnet and/or hornblende to hornblende-plagioclase-epidote with minor quartz and local diopside. Apatite and opaques are accessories.

At least two thermal events, based on radiometric Pb/U zircon ages, have affected the Baltimore Gneiss: the older between 1,000 and 1,200 m.y. ago, and the younger between 430 and 450 m.y. ago (Tilton and others, 1970; Grauert, 1973). Because some of the recovered zircons exhibit detrital outlines, (Tilton and others, 1970), the gneiss probably originated as a sequence of sedimentary and volcanic rocks (Hopson, 1964; Crowley, 1976) prior to 1,200 m.y. ago (Muller and Chapin, 1984).

Muller and Chapin (1984) determined that the Baltimore Gneiss had been affected by at least three periods of deformation. The first, designated as D_1, was the Grenville event of intense metamorphism and recrystallization that took place between 1,000 and 1,200 m.y. ago. The prominent layering of the gneiss is probably a Grenville-age transposition of original compositional layering. Tightly appressed vertical to reclined isoclinal folds within these layers may also be due to the Grenville event, but these have been overprinted and obscured by subsequent tectonism to the extent that they are difficult to distinguish from features of the next youngest deformation.

The second period of deformation, D_2, was divided into three phases of folding which may actually cover the continuous span of time (500-360 m.y.) encompassing the Taconic and Acadian orogenies (Muller and Chapin, 1984). The overall structural form and configuration of the gneiss anticlines as well as their cover rocks was established during this period. Isoclinal folds, refolded isoclines, and open folds with horizontal to gently plunging axes reflect stages in the formation of the gneiss nappes, followed by their refolding and vertical compression during uplift.

The third deformation, D_3, resulted in the production of brittle structures, and may be the near-surface expression of extensional strain during the Alleghenian-Palisades deformation of 260-190 m.y. ago (Muller and Chapin, 1984). Steeply dipping to vertical faults with breccias that exhibit evidence of hydrothermal activity transect the pre-existing structural features including the margins of the gneiss anticlines, but are themselves cut by diabase dikes of Triassic-Early Jurassic age.

Board bus and return to Cold Spring Lane, turn left (west) on Cold Spring.

44.2 Left (north) onto Hillen Rd.

44.3 Hillen becomes Perring Parkway. Continue north to Baltimore Beltway (I 695).

49.1 Enter Baltimore Beltway (I 695) West (toward Towson)

55.4 Outcrop and ridge on the left is in the Setters Formation.

55.6 Valley in the Cockeysville Marble (Minebank Run).

55.8 Marble outcrops on both sides of the road.

56.8 Ridge (Joppa Ridge) about a half mile to the south is the Setters Formation. The tall buildings are in downtown Towson.

59.3 Leave Baltimore Beltway (Exit 24) to I 83 North.
As we enter the interchange the hill directly in front of us is underlain by Lock Raven Schist.

61.0 Timonium Rd. Hills to the left are still Loch Raven Schist, the road and valley to the immediate right are in Cockeysville Marble and further to your right is the Texas Dome.

62.2 Padonia Rd. Loch Raven Schist outcrops on the side of the interchange on the left.

62.5- Large quarry operation in the Cockeysville Marble.

63.7 Genstar Corp. Texas Quarry (Stop 5 this trip).

65.1 Exit 20 Shawan Rd. (East)
Leave expressway.
The Industrial Park on the right is built on Cockeysville Marble. The hill ahead and to the left is the Phoenix Dome.

65.7 Turn left onto International Rd. (If you miss this turn take the next left.)

65.9 Left onto McCormack Drive.
Continue up hill. Outcrop on left is Setters Formation, Schist member.

66.4 Turn right into shopping center parking lot. Park at the outcrop end of the Macy's Lot. (For busses it is best to call the Hunt Valley Mall Security Office to obtain parking permission. If you wish to use the outcrop along the parking lot you also need to contact mall security.)

STOP 2 Hunt Valley Mall - Phoenix Dome

The outcrop featured at this stop is located in the south flank of the Phoenix Dome (Cockeysville, MD $7^1/_2'$ quadrangle). Construction of the parking area in 1980 resulted in uncovering a section of hillside nearly .7 km long and 10-15 m high exposing a considerable portion of the upper section of the Setters Formation, a small portion of the Cockeysville Marble (Crowley, 1976), and the contact between these two units. The outcrop has been terraced and so provides a lower level exposure parallel to the parking lot

road and an upper one along a less traveled connecting road (McCormack Rd.). The roads are subparallel to strike so that a west to east transect takes one up section.

Setters Formation

Crowley (1976) recognized three major lithologies which comprise the Setters Formation: a quartzite with abundant muscovite, a less common quartz rich gneiss, and a biotite-muscovite-plagioclase-quartz schist. The quartzite member was considered the basal unit of the formation. Its slabby weathering habit plus the occurrence of tourmaline crystals on the cleavage planes has made this a popular and easily recognized building stone in the Baltimore area. Only the schist member is exposed at the Hunt Valley outcrop. This upper-most unit has abundant garnet with either kyanite or staurolite indicating regional metamorphism of intermediate grade. Detailed studies on the compositional layering within garnet crystals from the Hunt Valley outcrop suggests alteration at a temperature of about 570°C under a pressure of about 6.5 kilobars (Lang, H., 1987).

The original sediments for the Setters varied from clean sands (quartzites) to clay-muds (mica schists). Such sediments are typical of those deposited in low-lying coastal regions in fluvial, beach, and near-shore environments.

Compositional layering and schistosity throughout the formation are remarkably parallel and further parallel that in the Baltimore Gneiss at the contact (Muller and Chapin, 1984). Multiple deformation can be recognized in this outcrop including development of original foliation, crenulation folds, warping of the entire set of units to form the dome (nappe), and the later development of NW-SE striking joints.

Cockeysville Marble

This thick carbonate unit (0-1.4 km) consists of several types of marble that vary in composition (calcite to dolomite) and grain size (coarse to fine). The distribution of rock types within the formation has not yielded a discernable stratigraphic sequence (Choquette, 1960) so that the members designated by Crowley (1976) cannot be interpreted in terms of relative age.

The basal unit exposed at the Hunt Valley outcrop consists of a fine to medium grained marble with silicate rich and pure calcitic layers interspersed with finer grained layers of similar composition but with dolomite. The silicate rich layers are tan due to the presence of abundant phlogopite while the calcite layers are pure white and are usually coarser grained. Darker colored, thin, wavy beds consist of quartz and tremolite. Minor feldspar and diopside have also been reported from this member. Throughout the formation pyrite is found as an accessory mineral and graphite has been reported on bedding planes in the phlogopitic member (Crowley, 1976). The marble weathers easily to form calcite and dolomite sands, and characteristically bright red soil. Joint controlled ground water solution is evident in this outcrop and is reported from the many quarries in this area. The Setters-Cockeysville contact does not reveal compositional grading (Choquette, 1960) but does reveal a continued parallelism of compositional layering in both units and with the contact. The contact at the Hunt Valley outcrop is now covered with saprolite and fill. However the cover is thin and the soils display an abrupt change from the

reddish-brown developed on the Setters to the bright red typical of that formed on the marble.

Depart mall area via service road, right onto McCormack Rd. to York Rd.

66.9 Turn right (south) onto York Rd.

67.4 Turn left onto Paper Mill Rd.

67.7 Ashland Presbyterian Church built of Cockeysville Marble.

67.8 Condominiums on left are recent development on the site of the Ashland Furnace property, an old iron foundry established for the processing of goethite ores found in this area.
Continue on Paper Mill Rd.

68.5 Hiking trail developed by Baltimore County along the right-of-way of the old North Central Railroad.

Pine plantations of the Loch Raven Reservoir watershed (Baltimore City property).

69.0 Outcrop of Loch Raven Schist on the right. Bridge crosses the head of the Loch Raven Reservoir, a main source of water for Baltimore City and parts of Baltimore County. The flats visible on either side of the Gunpowder River visible off the left side of the bridge are deltaic deposits. This was once the site of a broader stretch of reservoir known as Paper Mill Pond and is still shown as water on most maps.

69.6 Poplar Hill Rd.

69.7 Phoenix Rd. Turn left and park.

Walk back to Poplar Hill Rd. and up hill to outcrops. Post flag persons. This is a narrow winding road with scattered exposures at the road side .

EXERCISE CAUTION!

STOP 3 Poplar Hill Road, Loch Raven Schist

The Loch Raven Schist formerly was designated in the Piedmont of Maryland as the oligoclase-mica schist facies, or southeastern facies, of the Wissahickon Formation (Jonas and Knopf, 1925; Knopf and Jonas, 1929). The stratigraphy of these rocks was reinterpreted by Southwick and Fisher (1967) and they were renamed the lower pelitic schist facies of the Wissahickon Formation. A further revision lumped all the pelitic schists of the Wissahickon into simply the pelitic schist facies (Higgins and Fisher, 1971). Crowley (1976) gave the schists in the vicinity of the gneiss domes the formal name of Loch Raven Schist, and considered them to be the lowermost unit of the Wissahickon Group, itself a part of the Glenarm Super Group.

Although excellent exposures of the Loch Raven Formation are present in the eastern Piedmont of Maryland, especially in the deep gorges of the streams that cross the region, throughout much of its area of occurrence the schist underlies an upland area with a deep saprolite cover and is poorly exposed in areas of easy access for large groups. This outcrop along Poplar Hill Road is typical of the unit. Several ledges of the schist are exposed in the bank of the road. The rock is a medium-grained biotite-plagioclase-muscovite-quartz schist in which the muscovite flakes may be several times the size of the other mineral grains. Corroded crystals of garnet, ranging in size from 1/8 to 1/4 inch, are common. Small lenticles of clear to milky, light-gray quartz are present parallel to the foliation and interlaminated with the schist. Veins and pods of dark-gray to brown quartz, up to 1.5 feet thick, are both concordant and discordant with the foliation.

Throughout the exposure, the micaceous schist is interlaminated with thin layers of a more granular, quartzofeldspathic schist which Muller (1985) referred to as the Oella facies of Crowley (1976). Where this facies becomes the dominant lithology, Crowley (Crowley, Reinhardt, and Cleaves, 1976) mapped it as the Oella Formation.

Foliation in the Loch Raven Schist is steep to the south. This foliation has been tightly crinkled along closely-spaced cleavage planes that dip northward at a moderate angle.

Return to York Rd.

72.1 Turn left (south) on York Rd.

72.6 Cockeysville Underpass

74.1 Intersection with Church Lane
Prepare for left at nest traffic signal.

74.3 Left on Galloway Rd. (Follow sign for U of MD Extension Services and County Library.)

74.6 County Home Park, site of original county almshouse (the building at the top of the hill, built of Cockeysville Marble)

Park in area next to tennis courts.
(Restrooms available at west side of tennis courts.)

Up hill on the east side of the tennis courts is small outcrop of the mineralized zone of the Ruxton Fault.

STOP 4 County Home Park, Ruxton Fault and Lunch

The rock exposed at this stop is a light-gray to tan, dense, recrystallized quartzose breccia. It lies within a fault zone which Crowley (1976) considered to be an extension of the Ruxton Fault in northern Baltimore City and adjacent Baltimore County. Although

exposed along the western margin of the Texas anticline between the Baltimore Gneiss and the Cockeysville Marble, the rock does not resemble the muscovite-bearing, layered quartzite of the Setters Formation. However, it may represent recrystallized Setters or Baltimore Gneiss in which the original mineralogy has been thoroughly replaced by silica. Close examination of the rock shows it to be made up of many angular fragments which range in size from a fraction of an inch to several inches across, all tightly cemented with silica. Vugs within the rock are lined with drusy quartz and quartz crystals up to 1/4 inch in length.

This breccia and the Ruxton Fault represent an example of the brittle D_3 deformation of Muller and Chapin (1984) described at Stop No. 1. The rock fragments in the breccia appear to have been hydrothermally altered and the fractures have been healed with hydrothermally deposited quartz. The age of the deformation is later than the middle Paleozoic folding and metamorphism of the Texas gneiss anticline. It is assumed to have been formed sometime during the Alleghenian-Palisades deformation period, and most likely in the Triassic-Early Jurassic event because the strike of the fault and its near-vertical dip are approximately parallel to the trends of known Triassic faults in the Piedmont.

Return to York Rd.

75.0 Turn left (south) on York Rd.

75.3 Padonia Rd. turn right (west)

75.8 Entrance to Genstar Corp., Texas, MD quarry

STOP 5 Genstar Quarry, Texas, MD

Marble has been quarried in this area since the American Revolution with major development beginning in the second decade of the 19th century when material for the Washington Monument in Baltimore was obtained from the Beaver Dam quarry west of the current Texas pits. The original Beaver Dam quarry, now abandoned. supplied marble for several famous buildings including 108 twenty-six foot columns used in the National Capital, the top section of the Washington Monument in D.C., and the spires of St. Patrick's Cathedral in New York City. By 1847 there were 13 active pits in the Cockeysville area including several small pits which have evolved into the operation seen here today.

The original quarry was developed from a small older opening into a major crushed stone operation by Harry T. Campbell in the mid-1920's. Two major openings were developed by the 1960's when the Campbell Company became part of the Flintkote Company. A third pit was opened at the south end of the workings in the 1970's. The entire facility was acquired by the Genstar Stone Products Company in 1979. In the last few years the rock materials separating the three pits have been removed. An underground mine in the northern oldest portion of the pit follows a zone of very clean white calcite extracted for specialized chemical uses.

The major product of the quarry is crushed stone and calcite sand. The crushing, separation, and packaging all take place on site. The processing plant located at the north end of the property is a state-of-art computer automated operation. Quarry management is quite proud of their operation and invite school groups to tour the facility.

Two members of the Cockeysville marble described by Crowley (1976) are exposed within the quarry:

1. Massive Metalimestone -- massive units of coarse to medium grained calcite-rich and fine grained dolomite predominate. The dolomitic units tend to be gray (bluestone) and the calcite units are white. In places a very coarse grained metalimestone cuts across dominant foliation suggesting local mobilization of the rock during metamorphism. The metadolomite weathers to a tan color and contains more phlogopite (tan mica) than the metalimestone. Other silicates found in the dolomite include muscovite, tremolite, diopside, and quartz. Locally, large crystals of quartz and pyrite have been found in both units. The metalimestone weathers to a white calcite sand. Silicate minerals are rare but include phlogopite. muscovite, quartz, and tremolite. The extremely rare bright green mice, fuchsite, has been found in this unit. The thickness of this member is estimated to range from 0-1500 feet.

2. Layered marble member -- interlayered metalimestone and metadolomite in approximately equal amounts. Major and assessory minerals are as in the massive metalimestone. The major difference between the two members in thickness of the layers. The thickness of this member ranges from 0-650 feet.

Return to Padonia Rd. turn right (west) to entrance to I 83 South.
Loch Raven Schist outcrop on left side of ramp.

Continue on I 83 south to Baltimore Beltway.

78.8 Right lane for Baltimore Beltway (west)

Continue to Exit 23 Falls Rd south.

79.8 Exit 23 Fall Rd. South
Bear left after leaving ramp to make a left turn at the next traffic signal.

80.9 Joppa Rd. Left onto Falls Rd. south.

81.6 Weathered outcrop of Setters on the right.

82.4 Brooklandville, historic textile mill town now being "gentrified".

82.9 Outcrops of Lock Raven Schist (Oella lithology).

83.4 Coppermine Terrace.

Turn right into parking area next to old quarry. Passengers disembark. Bus proceed on driveway to Becton Industries parking area to turn around.

STOP 6 Bare Hills Serpentinite, Falls Rd. and Copper Mine Terrace

The name of this area is descriptive of the relatively sparse and stunted vegetation that is found on the thin and "infertile" soils that develop on serpentinites. The lack of thick stands of hardwoods normally found in this region is thought to be partially due to the poor water retention of the thin soils and, possibly, to the abundant Mg^{+2} released by weathering of serpentine minerals.

The quarry at this site, worked for crushed stone as recently as the 1960's, is all that remains of a once thriving mining district. Sometime between 1808 and 1828, Issac Tyson, Jr. discovered and developed chromite deposits in the serpentines on his farm near here. Chrome ore was produced from this area until abandoned in 1833. These deposits along with those of the Sykesville/Soldiers Delight districts also discovered by Tyson made Maryland the major source of the world's supply of chrome from the 1820's to 1860 (Knopf and Jonas, 1929). One of the largest copper mines in the state existed near here in the adjacent metagabbro unit of the Baltimore Mafic Complex. Nothing visible remains above ground to mark this mine which was opened in 1845 and operated intermittently until 1880.

The greenish black rock of the quarry is predominantly antigorite with "ghosts" of the original olivine visible in some thin sections. The rock mass has well developed joints and faults with slickensided surfaces, some with bright green williamsite. Other minerals occasionally found here include a reddish form of massive bronzite imbedded in blue-green serpentine, finely disseminated brown-black chromite, and seams of white asbestos. Various carbonate alteration products are also found: white magnesite as crack fillings, malachite and azurite coatings on weathered surfaces.

Return north on Falls Rd to Baltimore Beltway.

85.5 Right onto I 83 (Follow sign for Beltway)

85.8 Beltway West (Pikesville)

91.4 Pass intersection with I 795

97.7 Leave Beltway at Exit 15 West, U.S. Rte 40

Prepare for left at third traffic signal.

98.6 Left on Rolling Rd.

Oella Formation outcrop on right just before intersection at the second traffic signal.

98.2 Right at second traffic signal, Old Frederick Rd.

100.2 Right on Frederick Rd.

100.6 Old quarry on right in Ellicott City Granodiorite

100.8 Pull to side of road and park in front of the construction site nest to A&E Floor Supply

STOP 7 Ellicott City Granodiorite

The exposures of the Ellicott City granodiorite visible along Frederick Road are near the margin of the pluton intruded into the Oella (Wissahickon) Formation which is locally highly granitized. The fabric commonly found along the margin of the pluton has been interpreted as folding and mineral alignment developed during emplacement rather than as the result of later tectonism (Sinha, 1988). The major mineralogy of the pluton consists of plagioclase, alkali-feldspar, quartz and biotite with primary epidote among the assessory minerals (Sinha, 1988). Hopson (1964) noted that the pluton generally grades from a dark nonporphyritic granodiorite at the margins toward a lighter porphyritic granite at the interior similar to the compositionally zoned granitoids of the Sierras. A U-Pb zircon age of 458 m.y. is similar to those ages found for other middle-late Ordovician intrusives of Central Appalachian Piedmont terranes (Sinha, 1988). The genesis and movement of the magma is thought to be the result of local partial melting under moderate to high pressures as indicated by the presence of primary epidote (Sinha, 1988). The likely parent material may have been volcaniclastics or graywackes. Sinha (1988) suggests this origin from widespread occurrence of sphene, magnetite, and hornblende which indicate an oxidized source material.

In context of the changing tectonic picture in this area during the early Paleozoic the emplacement of this pluton was preceded by a metamorphic event (470 m.y.) that altered the plutonic Port Deposit tonalite in Cecil County, and an island arc phase represented by the 515 m.y. old James Run Formation (Sinha, 1988).

Continue west on Frederick Rd (Main St.)

101.2 Ellicott City - Historic town noted for textile and flour mills and site of the original first stop of the Baltimore and Ohio RR.

101.5 Right on Ellicott Mills Rd.

102.0 Left on Court House Rd.

103.7 Cross Route 40 (Court House Rd becomes MD 99)

104.4 Metagabbro outcrop on left (boulder in yard)

104.8 I 70 overpass

104.9 Right on Old Frederick Rd.

105.2 Descend into Patapsco River Valley

105.5 Park to the right just off road across the railroad tracks and before bridge.

Patapsco River, Baltimore/Howard County Line

Walk to outcrop across bridge and along old railroad right-of-way. Note segments of old stone "tracks" found near path.

STOP 8 Hollofield, Baltimore Mafic Complex - Hollofield Layered Ultramafite

This stop is the type locality of the Hollofield Layered Ultramafite as described by Crowley (1976). Mafic and ultramafic rocks interlayered on a scale ranging in thickness from centimeters to tens of meters are exposed in the quarry face. Hopson (1964) considered the layering to be of igneous origin, formed by crystal settling or by differential flowage within a large mafic pluton. However, Alterman (1987) considers the layering to be of tectonic origin, formed at the base of the Baltimore Mafic Complex where it has been thrust over the schistose rocks of the Wissahickon Group to the west. The fault contact is shown by Crowley and Reinhardt (1980) to lie immediately to the west on the opposite side of the Patapsco River from the quarry. Rhythmic layering of undoubted igneous origin can be found elsewhere in the Baltimore Complex (Hopson, 1964; Southwick, 1970; Hanan and Sinha, in press).

Crowley (1976) considered the predominant rock type in the quarry face to be actinofels and actinolite schist, but he added that as much as one-third of the exposure is interlayered amphibolite, called metagabbro in Hopson's (1964) measured section. In places, the rocks contain relict olivine and pyroxene which provide direct evidence of igneous origin. Tremolite and anthophyllite also occur with the actinolitic rocks. Black serpentinite, called metaperidotite by Hopson (1964), is a subordinate rock type and locally may contain talc. All of these rocks contain chlorite in varying amounts; some of the schistose rocks are almost entirely chlorite.

The quarry face has weathered considerably and has become obscured by vegetation since the section was described in detail by Hopson (1964), but the layering and textures are still recognizable.

MEASURED SECTION OF LAYERED ULTRAMAFIC ROCKS
Baltimore Gabbro Complex

(From: Hopson (1964): Table 32, pages 138-139.)

Location: Quarry, Patapsco River at Old Frederick Road, half a mile south of Hollofield, Baltimore County.

Geology: The quarry exposes a small part of a thick section of metamorphosed ultramafic rocks, near the base of the Baltimore Gabbro Complex. The upper part of the quarry is in massive metapyroxenite, the lower part in thinly interlayered ultramafic and gabbroic rocks. The measured section is 69.4 feet thick and consists of metapyroxenite 69.1%, metagabbro and mafic gabbro 15.7%, metaperidotite and metadunite 14.1%, chlorite-garnet rock 0.7%, and meta-anorthosite 0.4%.

Measured Section	
16 feet	***Metapyroxenite*** (pale green amphibole + colorless chlorite; minor magnetite). Massive, with no well-developed foliation or lineation. Cut by joints and small shears. Top not exposed.
2 feet	***Metapyroxenite*** (anthophyllite + tremolite; minor relict clinopyroxene and olivine, Mg-chlorite, opaques). Massive, originally coarse-grained rock.
2 feet	Thinly interlayered ***metaperidotite*** (mesh serpentine, relict olivine, chromite; lesser tremolite, Mg-chlorite, magnetite) and ***metapyroxenite*** (chiefly anthophyllite, tremolite). The layers range from 11/2 to 6 inches thick, but most are 1 to 2 inches. Contacts between layers are sharp.
4 feet	***Mafic metagabbro*** (pale green hornblende + bytownite). Massive, fine-grained, granoblastic. Rests in sharp planar contact on underlying 4-inch peridotite layer. There is a faint layering within the gabbro, and near the middle a 3/8-inch layer of coarse metapyroxenite.
4 feet	Thinly interlayered ***metaperidotite*** (serpentine + olivine; lesser treemolite, Mg-chlorite, chromite, magnetite, carbonate) and ***metapyroxenite*** (chiefly tremolite, anthophyllite, minor mg-chlorite). The peridotite was olivine-rich. The metapyroxenite layers are thicker (1 to 10 inches) than most of the metaperidotites (1/4 to 4 inches). Contacts between layers generally sharp, but commonly the layers are thickened, thinned, or pinched off.
1 1/2 feet	***Metapyroxenite*** (anthophyllite + tremolite; minor relict clinopyroxene and olivine, Mg-chlorite, opaques). Massive. Uniform in thickness across the quarry face.
1 foot	Thinly interlayered ***metaperidotite*** (chiefly serpentine, relict olivine, tremolite) and ***metapyroxenite*** (chiefly pale green amphibole). Individual layers 1/4 to 2 inches thick.
10 inches	***Metapyroxenite*** (chiefly pale green amphibole). Shearing and possibly some hydrothermal alteration. Schistosity oblique to layering.
10 inches	***Metaperidotite*** (serpentine, relict olivine, tremolite; minor chromite and Mg-chlorite). Massive and uniform.
4 inches	***Metapyroxenite (?)*** (pale green amphibole; minor Mg-chlorite). Massive; fine-grained. Possibly hydrothermally altered.
8 inches	***Metaperidotite*** (serpentine, relict olivine, tremolite, minor chromite and Mg-chlorite). Massive.
8 inches	***Metapyroxenite***, possibly with some shearing and hydrothermal alteration. Schistosity oblique to layering.
10 inches	***Metaperidotite*** (chiefly olivine; lesser serpentine, tremolite, chromite, and Mg-chlorite). Massive and uniform. Contact with underlying metapyroxenite is sharp but irregular.
3 feet	***Metapyroxenite***. Massive. Cut by small fractures, with alteration to very pale green amphibole and chlorite.
0-3 inches	***Amphibole-chlorite rock***. Very fine grained and massive, but patchy and heterogeneous-appearing. Pinches and swells; irregular contacts with enclosing layers.
5 feet	***Metapyroxenite*** (tremolite + anthophyllite; minor Mg-chlorite and opaques). Massive, originally coarse-grained rock. The lower 2 inches is richer in chlorite and strongly schistose; schistosity transects layering. Small shears with chlorite developed along them cut the massive rock.
2 inches	***Chlorite-garnet rock***. Coarse massive chloritic layer, with large clots of coarse reddish garnet. Contact irregular with underlying metagabbro.
1 foot	***Mafic metagabbro*** (pale green hornblende + bytownite). In sharp planar contact with underlying rock. Weak foliation, dipping about 20-30° more steeply than the layering.
8 inches	***Metapyroxenite*** (pale green amphibole; with lesser Mg-chlorite). Strongly schistose; schistosity parallels layering in the interior, but near the base it refracts steeply toward the underlying metagabbro. Thin discontinuous zones of coarse chlorite-garnet rock developed along the upper and lower contacts. This entire zone appears to be one of shearing and strong hydrothermal alteration.

2 feet	***Mafic metagabbro*** (70% pale-green hornblende, 30% bytownite). Lowermost 8 inches is feldspathic metapyroxenite, with some thin layering; grades upward into the more uniform mafic metagabbro. Contains small metapyroxenite inclusions. Weak foliation transecting the primary layering at a low angle.
1 1/2 inches	***Metapyroxenite*** tremolite-actinolite; minor Mg-chlorite, magnetite). Very fine-grained and massive. Grades abruptly downward into the underlying coarse metapyroxenite.
2 1/2 inches	***Metapyroxenite*** (tremolite + anthophyllite; minor Mg-chlorite, magnetite, carbonate). Massive and coarse-grained.
3 inches	***Chlorite-garnet rock.*** Coarse chlorite, with large clots of coarse pinkish-red garnet. No foliation. This rock is in sharp but very irregular embayed contact with the underlying anorthosite, and locally cuts down discordantly across it. The rock appears to be a product of hydrothermal alteration along a shear zone parallel to primary layering.
1-3 inches	***Anorthosite*** (bytownite; minor hornblende). Very fine-grained; granoblastic. Rests on the underlying gabbro in sharp planar contact.
4 inches	***Mafic metagabbro*** (85% hornblende, 15% bytownite). A thin feldspathic layer at the base. Well developed foliation transects layering at about 20°.
3 1/2 feet	***Metagabbro*** (pale green hornblende + bytownite; minor Mg-chlorite). Weak layering: alternating mafic and felsic layers, 6 inches to 1 foot thick. Foliation transects primary layering at a 20° angle.
3 feet	***Metapyroxenite*** (light-colored patches chiefly pale green amphibole; darker patches chiefly blue-green hornblende + minor Mg-chlorite. Rocks fine-grained with patchy coloration. Strongly sheared locally, with chlorite abundant along the shear zones. No well-developed foliation or lineation. Grades downward into the coarser, more massive metapyroxenite beneath.
4 1/2 feet	***Metapyroxenite.*** Massive. Sharp planar contact with thin metadunite layer of the underlying zone.
14 inches	Thinly alternating layers and lenses of ***metapyroxenite*** (tremolite + anthophyllite; minor chlorite, serpentine, relict olivine and ***metadunite*** (mesh serpentine with relict olivine; minor magnetite, chromite, carbonate, chlorite). Most layers range from 1/2 to 2 inches thick; one very continuous dunite layer 1/2 inch thick. Contacts between layers sharp and planar to ragged and irregular. Chiefly massive, but locally there is a weak schistosity at low angles to layering.
3 feet	***Metaperidotite*** (serpentine + relict olivine + tremolite + anthophyllite; minor Mg-chlorite, chromite, magnetite). Outlines of original coarse pyroxene. No foliation or lineation. Contact with underlying layer not well exposed.
6 feet	***Metapyroxenite*** (tremolite + anthophyllite; minor chlorite, opaques, carbonate). Composition and grain size uniform; no foliation or lineation. Base of layer not exposed.

69.4 feet total thickness

Return on Frederick Rd west to MD 99.

107.4 Right on MD 99.

107.5 Cross MD 29.

Rolling countryside developed on a variety of "Wissahickon" lithologies.

113.8 Marble valley at west end of Woodstock Dome.

115.3 Man-made hill to left -- Marriottsville Rd. landfill.

117.0 Right on MD 32 (north).

120.0 Left - follow sign for Main St.

120.4 South Branch of the Patapsco River.

Park in lot at liquor store at the intersection of Main St. and River Road.

STOP 9 Sykesville, Sykesville Formation

The Sykesville Formation at this stop is a medium- to coarse-grained, gray, massive to weakly-foliated biotite-plagioclase-quartz gneiss which is deceptively granite-like in appearance. It is composed of quartz, plagioclase, biotite, and muscovite, with accessory magnetite, garnet, chlorite, and epidote. The many included fragments of quartz and fine-grained, dark-gray schist ranging in size from granules to boulders and slabs. Muller (in prep.) lists the rock types found as clasts in the Sykesville, in order of decreasing abundance, as:

1. vein quartz
2. medium-grained garnet-mica schist
3. fine-grained micaceous graywacke
4. fine-grained, buff to light-gray garnet-hornblende-epidote and garnet-biotite=epidote quartzite
5. garnet-chlorite-biotite schist with felsic segregations and veins
6. amphibolite
7. ultramafic rocks, including chlorite-amphibole schist with or without talc, and epidote fels.

The rock exposed in the vicinity of this stop was originally named the "Sykesville Granite" by Keyes (1895) and was characterized by the presence of "inclusions" of the surrounding schistose country rocks. Cloos and Cooke (1953) recognized the "inclusions" as clasts of sedimentary origin and renamed the unit the Sykesville Formation. Hopson (1964) described the formation as a group of pebble- and boulder-bearing arenaceous to pelitic metamorphic rocks, originating as a heterogeneous mixture of unconsolidated sediments, and fragments of lithified sedimentary rocks and volcanic rocks. Muller, Candela, and Wylie (1989) interpret the Sykesville to represent a thick blanket of poorly bedded, mass-flow and slump debris, deposited as part of a tectonic melange in advance of an obducting forearc terrane.

END

Return to Silver Spring via MD 32 to MD 29.

MD 29 southwest to I 495.

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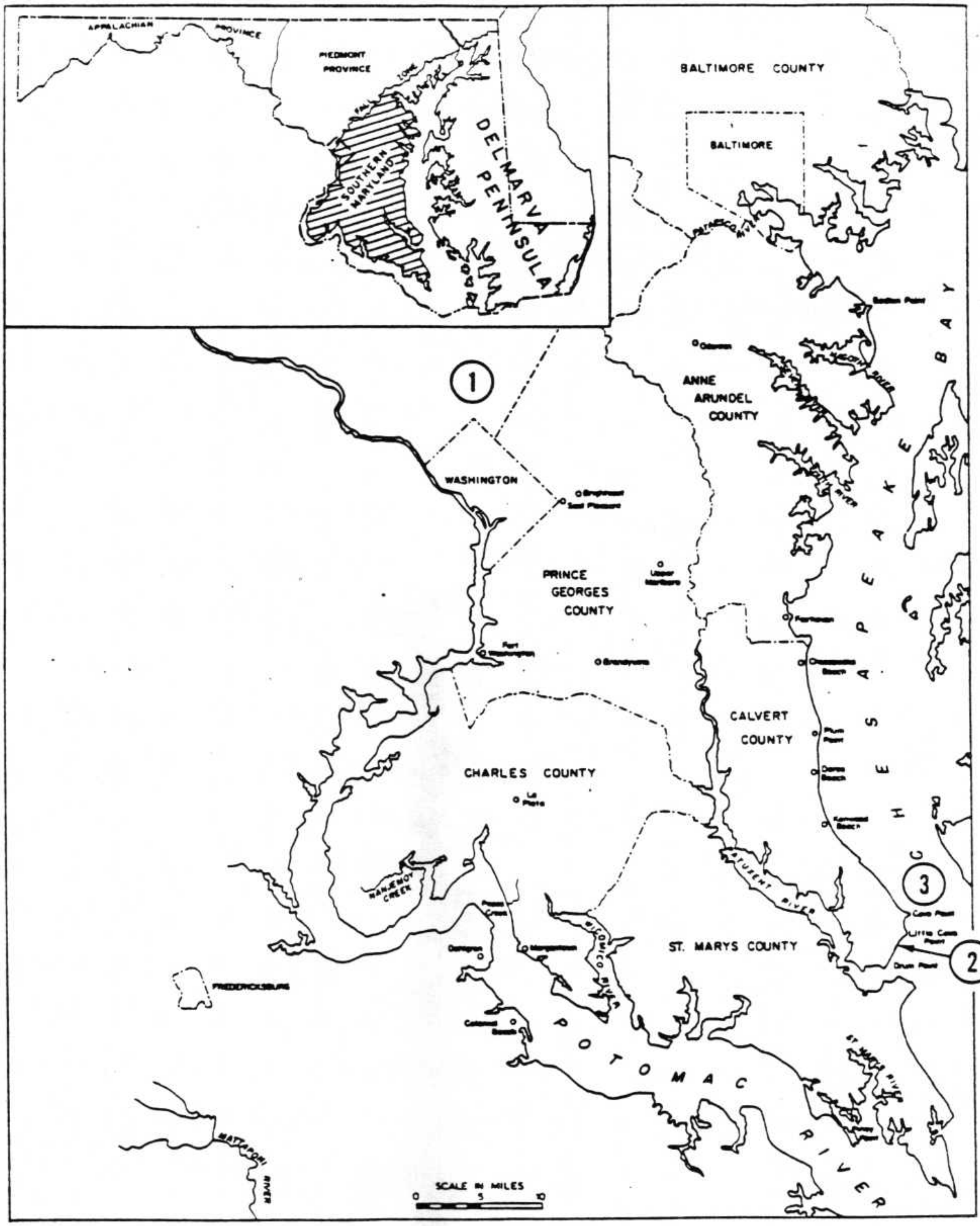

Figure 1. Index map of Southern Maryland showing geographic names employed in text. Adapted from Glaser, John D., 1968, Maryland Gedlogical Survey Guidebook 1.

THE CLIFFS OF CALVERT

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INTRODUCTION

The Miocene rocks of the Chesapeake Bay region are widely regarded as the best fossil-bearing marine deposits of that age anywhere in the world. The rock sequence is thick, outcrops are extensive, and well-preserved fossils are abundant.

The most well-known and most extensive outcrops are those along Calvert Cliffs. The Cliffs stretch from Fairhaven in Anne Arundel County south almost to Drum Point in Calvert County, in places exceeding 100 feet in height. Additional large outcrops occur along the Potomac River's Virginia shore, and numerous other localities are along many of the rivers and streams tributary to the Chesapeake Bay.

Fossils have been collected in the Maryland Miocene since before 1770, when an illustration of what is now known as Ecphora gardnerae appeared in a European publication. This drawing is one of the first published accounts of a New World fossil.

More than 600 species of fossil plants and animals have been found in the Bay region since colonial times, ranging in size from microscopic specimens (such as diatoms, pollen grains, radiolarians, foraminifera, and ostracodes) to whales. Most obvious are the mollusks, some beds being made up almost entirely of their shells. Other invertebrates include corals, barnacles, crabs, and sand dollars. Vertebrates are common, especially shark teeth and bones of whales and porpoises. Sea turtles, crocodiles, birds, sea cows, seals, and land mammals round out this amazing treasure from the geologic past.

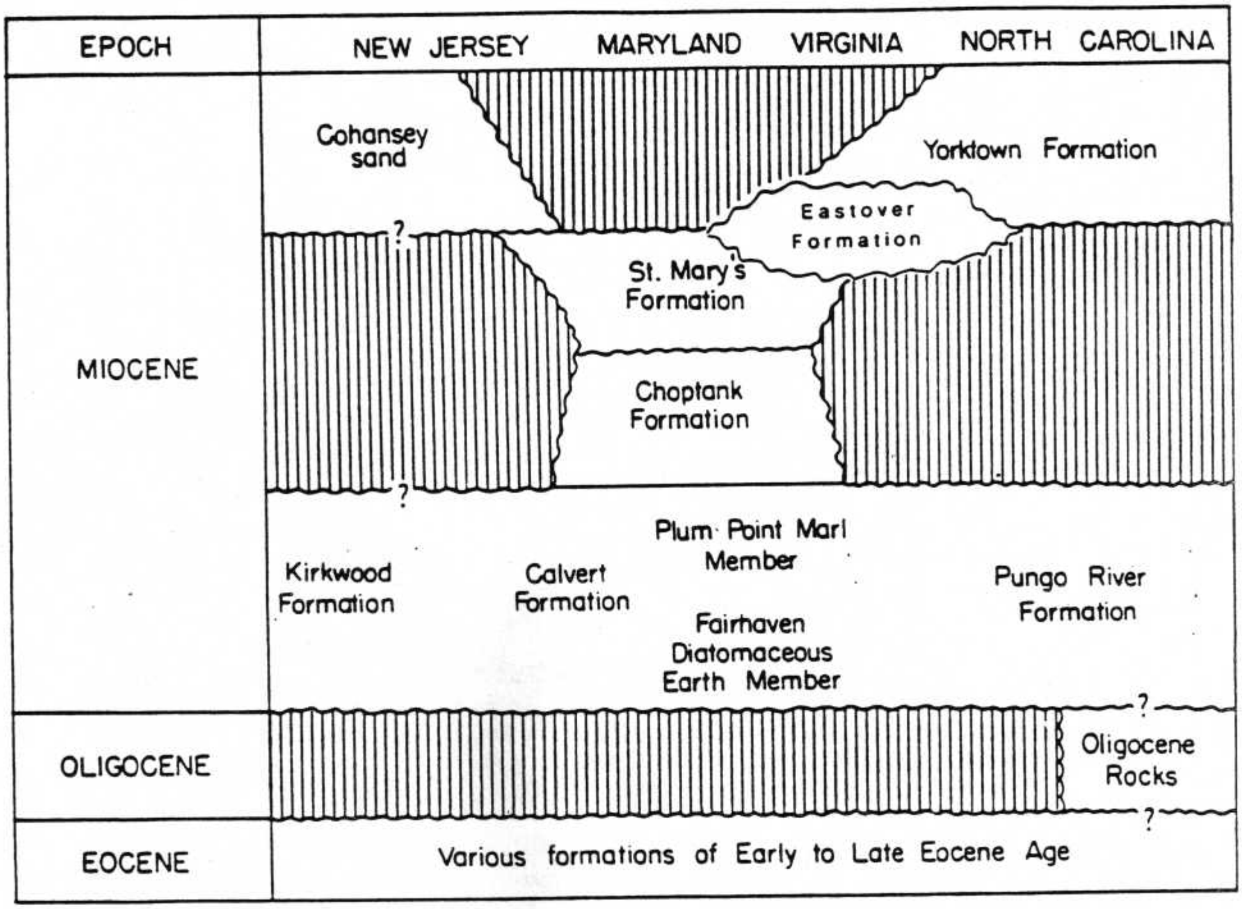

Figure 2. Chart showing relationship of Miocene formations from New Jersey to central North Carolina. Vertical lines indicate nondeposition.

Adapted from Gernant, R. E., T. G. Gibson, and F. C. Whitmore, Jr., 1971, Maryland Geological Survey Guidebook 3.

STRATIGRAPHY

The Miocene deposits of Maryland are part of the Chesapeake Group, a richly fossiliferous accumulation of marine rocks. Three formations occur in Maryland: from oldest to youngest they are the Calvert Formation (named after Calvert County on Maryland's Western Shore of Chesapeake Bay, where the extensive exposures of Calvert Cliffs occur); Choptank Formation (after the Choptank River of Maryland's Eastern Shore); and the St Marys Formation (after the St Marys River of St Marys County, Western Shore). Some younger formations, the Eastover and Yorktown, occur across the Potomac River, primarily in Virginia. In Maryland, outcrops arguably attributed to the Eastover and Yorktown are unfossiliferous. See figures 2-6.

After naming the Calvert, Choptank, and St Marys formations in 1902, George B. Shattuck later (1904) subdivided the Calvert Formation into the older Fairhaven Diatomaceous Earth Member, and the younger Plum Point Marl Member. Shattuck also divided all the rocks then included in the Chesapeake Group (the Eastover and Yorktown formations were described later) into 24 "zones." These "zones" are no longer considered to be true biostratigraphic units, but such distinctions are still useful, and Shattuck's "zones" are now generally referred to as "beds." Some of these <u>beds</u> have been given <u>member</u> status, and the boundaries of the formations have been moved from the horizons where Shattuck placed them. Some beds are of such local occurrence and are so hard to recognize that they have been combined (note particularly Beds 4 through 9). Figure 7 summarizes current thinking on the Miocene stratigraphy of Maryland.

The entire sequence of the Chesapeake Group dips gently to the southeast at about 11 feet per mile (with some local variation and, in places, even reversal of dip). As a result, one sees progressively younger rock units at beach level as one travels <u>south</u> along Calvert Cliffs (down-Bay). See figure 8. Therefore, the beds one will see in outcrop largely depend upon where one stops along the 30-mile-long exposure of Calvert Cliffs. The same is true of the fossils. For example, shark teeth increase in abundance and variety as one travels the beach <u>north</u> along the cliffs. The reason for this increase is that vertebrate remains, including sharks, are most common in the Calvert Formation, which has its greatest exposure at the north end of the Cliffs.

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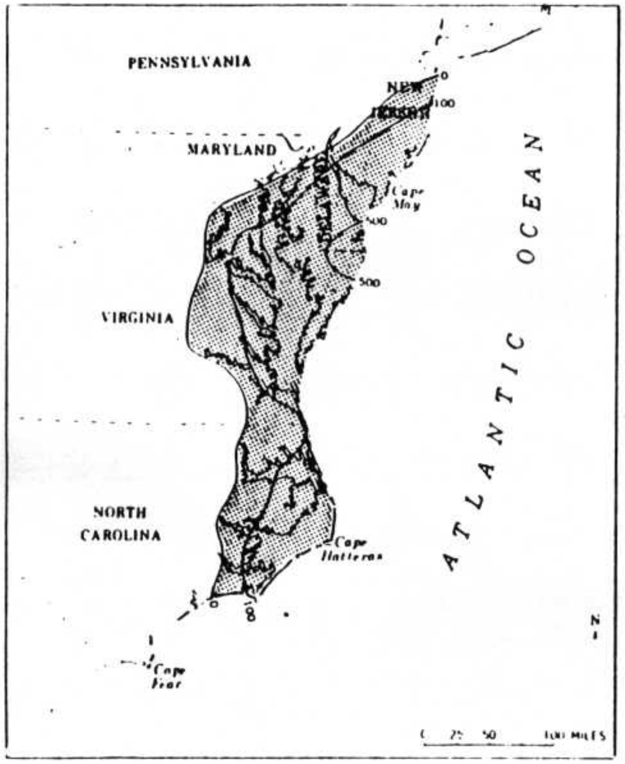

Figure 3. Isopach map of Calvert Formation and equivalent strata. Contours are in feet (from Gibson, 1970).

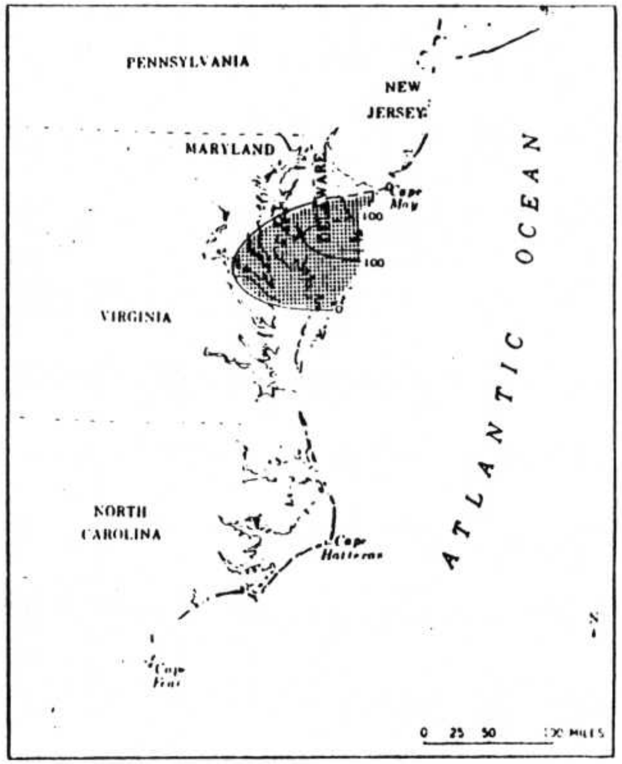

Figure 4. Isopach map of Choptank Formation. Contours are in feet; contours are dashed where approximately located (from Gibson, 1970).

From Gernant, R. E., T. G. Gibson, and F. C. Whitmore, Jr., 1971, Maryland Geological Survey Guidebook 3.

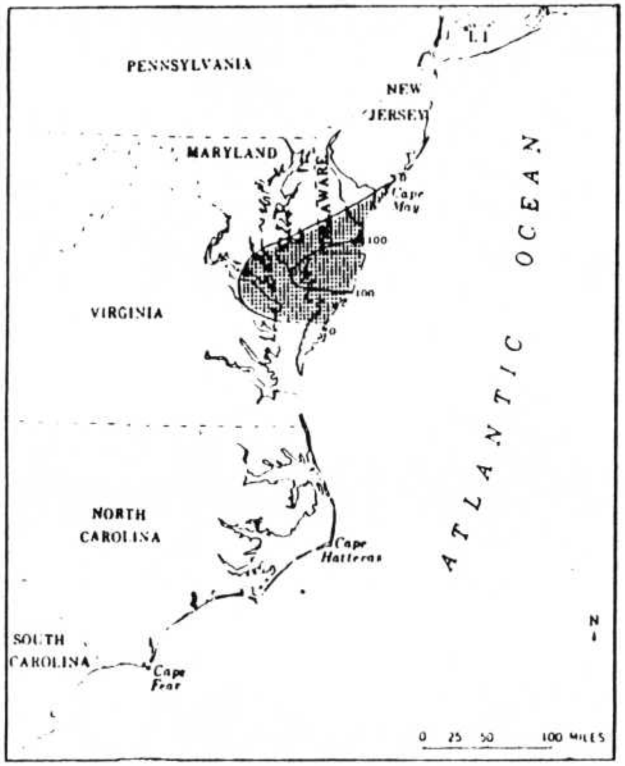

Figure 5. Isopach map of St Marys Formation. Contours are in feet; contours are dashed where approximately located (from Gibson, 1970).

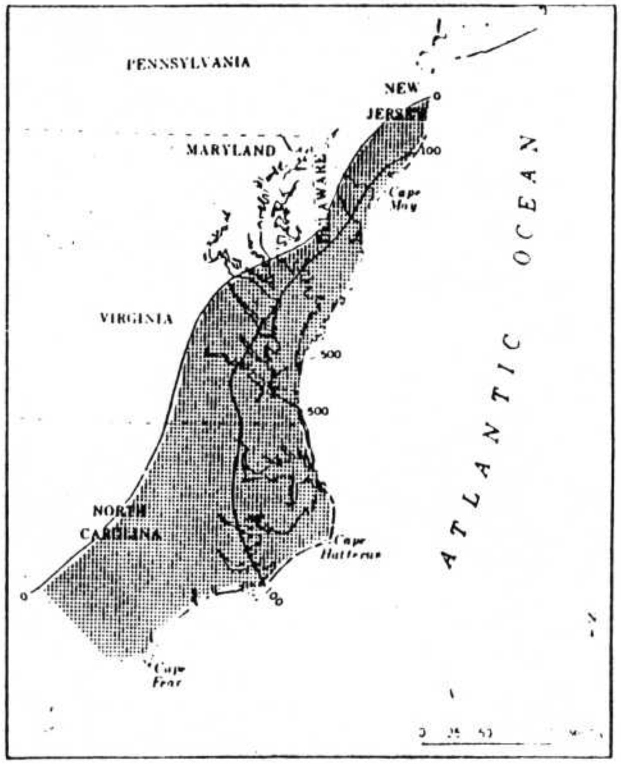

Figure 6. Isopach map of Yorktown Formation and equivalent strata. Contours are in feet; contours are dashed where approximately located (from Gibson, 1970).

From Gernant, R. E., T. G. Gibson, and F. C. Whitmore, Jr., 1971, Maryland Geological Survey Guidebook 3.

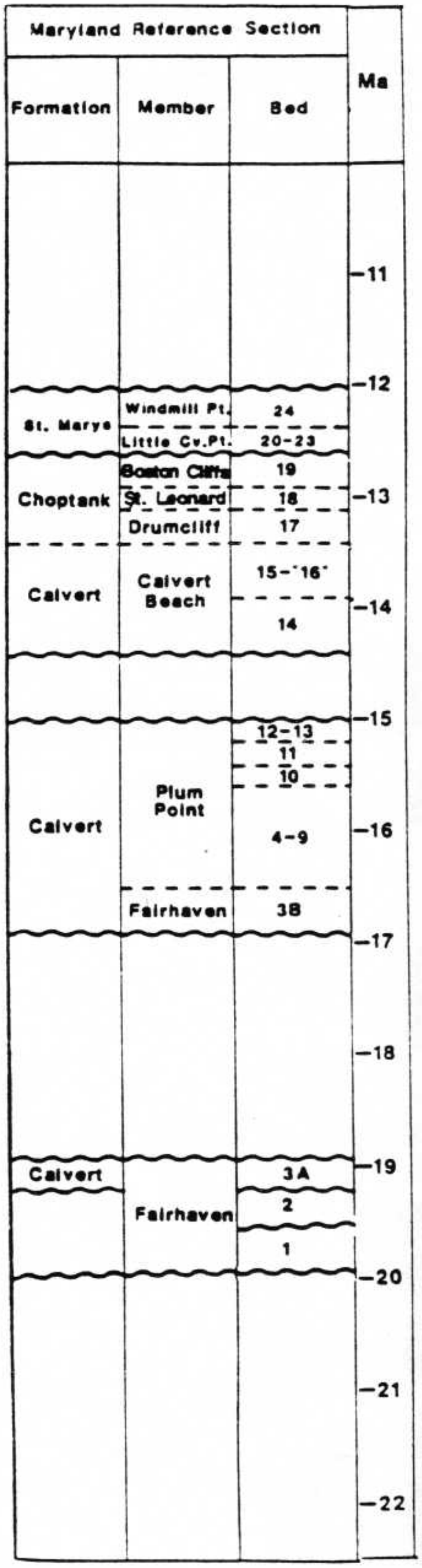

Figure 7: Composite stratigraphic section of Maryland Miocene. Some authors call Bed 2 the Popes Creek Sand Member. Bed 1 probably on Miocene- Oligocene boundary. Modified from Andrews (1938)

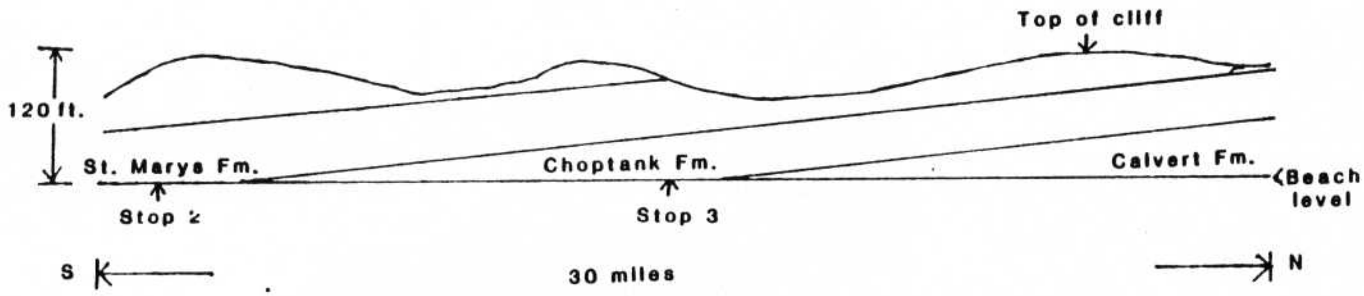

Figure 8: Diagram showing regional dip. Extreme vertical exaggeration

DESCRIPTION OF STOPS

STOP 2: North of Driftwood Beach, Chesapeake Ranch Club (south of Little Cove Point, Calvert County, Maryland). Private: entry courtesy of Chesapeake Ranch Club.

The lower, gray-colored portion of the cliff contains abundant fossil mollusks; this is the Little Cove Point Member (Beds 21-23) of the St Marys Formation. The snail, Turritella plebia, is the most abundant representative of a diverse fauna of gastropods and bivalves. Other invertebrates present are barnacles, occasional pieces of coral, and brittle stars. Vertebrates are less common, although otoliths of bony fish and other bone can usually be found. Occasionally, remains of both marine and land mammals, turtles, and crocodiles are visible. This is a good locality to find specimens of Maryland's official state fossil shell, Ecphora gardnerae.

An unconformity can be seen on fresh surfaces near the base of the cliff, where gray silt overlies gray clay. The top of the gray clay is burrowed - notice the burrow filling is the same as the overlying gray silt. From this evidence, can you determine where the burrowers lived, and when they were alive? Look both here and higher up the cliff for the peculiar corkscrew-shaped burrows of Gyrolithes marylandicus, an enigmatic ichnofossil (trace fossil). The identity of this burrow-maker is an open question, although current theory interprets these structures as annelid worm burrows.

The upper orange-colored sand contains few if any fossils, and for that reason it is of debatable age. One authority interprets these upper beds as a beach deposit which is a continuation in the same regressive cycle as the Little Cove Point Member. This interpretation would make the upper sands here equivalent to the Windmill Point Member (Bed 24), which is very fossiliferous elsewhere. Another authority believes them to be part of a later Miocene cycle, perhaps an Eastover Formation equivalent. Whatever their age, one obvious primary sedimentary structure is the cross bedding that can be seen in some portions of this unit.

STOP 3: Camp Bay Breeze, Calvert Cliffs State Park, Maryland (Camp Bay Breeze available by prior arrangement only - see "Fossil Localities"). Entry courtesy of Maryland Park Service.

The fossils here are primarily in the Boston Cliffs Member (Bed 19) of the Choptank Formation. The scallop, Chesapecten nefrens, is the most abundant and best preserved taxon. Other bivalves and some gastropods are common, but they are less well-preserved and harder to collect. The Choptank is sandy here, and orange in color.

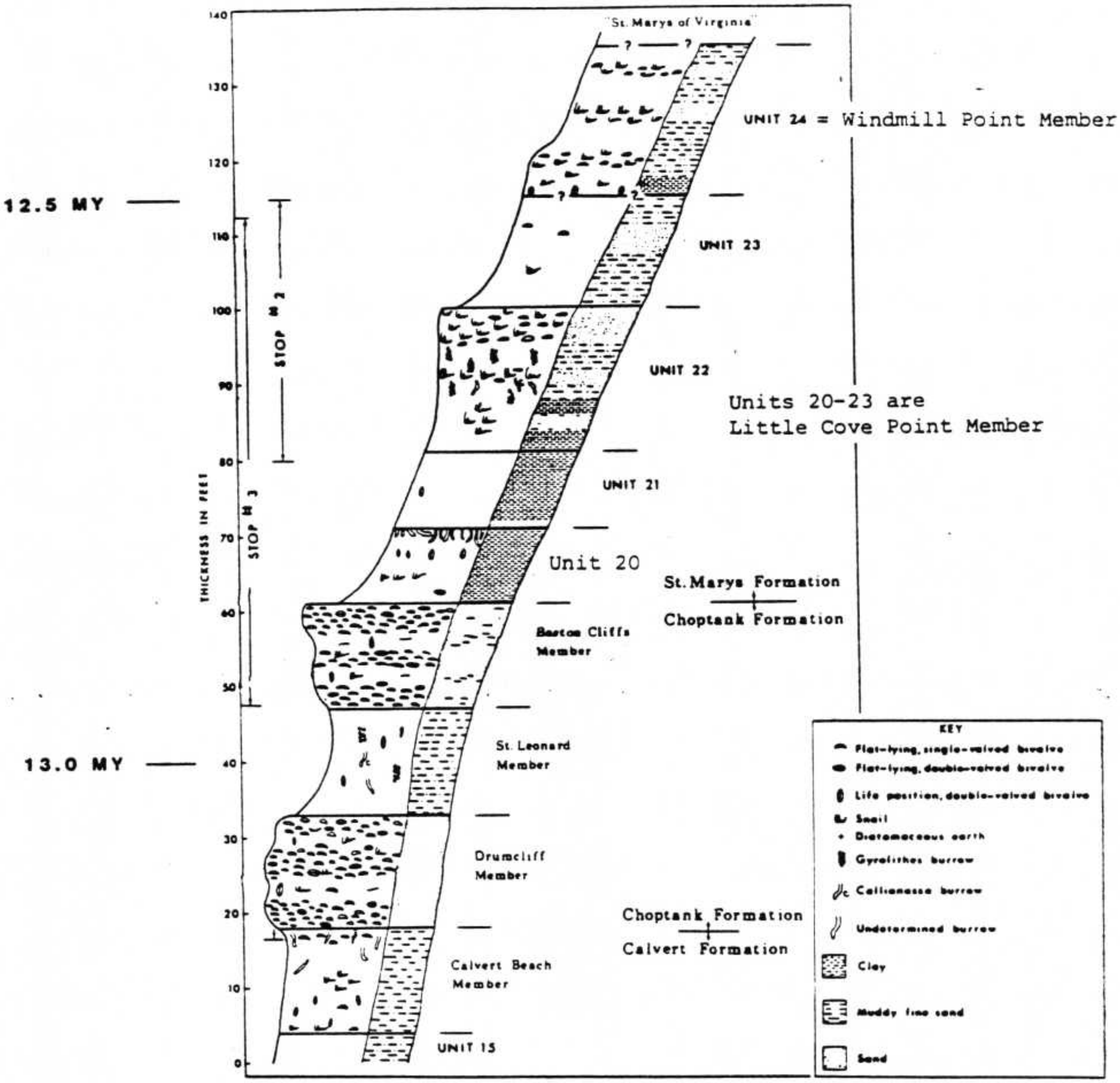

Figure 9: Generalized stratigraphic column for the Middle Miocene Choptank and St. Marys Formations of Maryland. Illustrates both typical fossil distribution and sediment types. Unit numbers to right refer to Shattuck's (1904) stratigraphic designations. Names Calvert Beach, Drumcliff, St. Leonard, Boston Cliffs, and Conoy designate individual members of the Choptank Formation as described by Gernant (1970). Double-headed arrows to left point out stratigraphic sections seen at Stops #2, 3, and 4.

Adapted from Gernant, R. E., T. G. Gibson, and F. C. Whitmore, Jr., 1971, Maryland Geological Survey Guidebook 3.

Above Bed 19 the gray-colored Little Cove Point Member (Beds 20-23) of the St Marys Formation is exposed. It is muddier in its lower part (Beds 20 and 21) than the Boston Cliffs Member (Bed 19) below, and largely unfossiliferous. Higher up the cliff are the same unfossiliferous sandy beds of questionable age seen at Stop One.

SPACE FOR NOTES

COLLECTING TIPS

Plan to get wet and dirty. A pair of sneakers you are willing to get wet will protect your feet from sharp objects. In cold weather, or if you prefer to stay dry below the waist, hip boots are the only answer. Depending on your tolerance of the sun, consider a wide-brimmed hat, sunglasses, and sun-tan lotion.

A canvas collecting bag with shoulder straps to keep your hands free will make carrying your finds much easier. Wet fossils, especially small ones, are easily lost in pockets; vials and 35mm film containers are excellent for storage. Many fossils are fragile, so bring wrapping tissue to pad them (a roll of toilet paper works fine - store it in a waterproof bag).

For digging in blocks that have fallen from the cliff, an oyster knife, screw-driver, or garden trowel is helpful. Fossils still within the rock matrix are especially fragile. Do not bother to dig until you see something exposed; then dig around the specimen and take some surrounding matrix back with you to help hold the specimen together. Most fossils will be stronger when they are dry, so wait until you get home to clean them.

Labels, notebook, and waterproof pens and pencils will round out your gear.

Always respect private property: do not climb or dig in the cliffs or cross private property on the way to the beach without permission of the property owner. On public lands, the same precautions apply with respect to the cliffs as do on private property.

Injuries and death from falling cliffs or blocks have occurred at Calvert Cliffs. Falls occur more frequently in the winter and early spring but can **HAPPEN AT ANY TIME WITHOUT WARNING** and without visible overhangs or cracks.

<u>STAY AWAY FROM OVERHANGS OR UNSTABLE CLIFFS</u>! Be aware **AT ALL TIMES** of where you are in relation to the cliff above you.

Collecting is generally best at low tide. A wind out of the northwest can contribute to especially low water, and especially good collecting. The worst conditions occur when the wind is out of the southeast, because it pushes the Bay water against the Western Shore.

FOSSIL LOCALITIES

The following fossil localities are currently (March, 1989) open to the public. All restrict collecting to beach flotsam and jetsam or cliff blocks fallen on the beach. **DO NOT CLIMB OR DIG IN THE CLIFFS WITHOUT PERMISSION!** Localities are listed north to south.

1. Breezy Point beach, Calvert County, Maryland. Maryland Routes 2 and 4 to Maryland Route 260 east, Maryland Route 261 south, east on Breezy Point Road. Bathing beach, admission charge. Calvert Formation, shark teeth common in gravel.

2. Matoaka Cottages, Calvert County, Maryland. Maryland Routes 2 and 4 to Calvert Beach Road east; left on dirt road marked with sign to "Matoaka Cottages." Day use, $3.00 per head for adults, $1.00 for children under 12 - cottages and camping also available. Choptank Formation, good variety of mollusks and other invertebrates, fair for shark teeth and bone. Larry and Connie Smith. Phone: (301) 586-0269.

3. Flag Ponds Nature Park, Calvert County, Maryland. Maryland Routes 2 and 4 to sign for "Flag Ponds Nature Park" (east). Admission: $3.00 per car, $10.00 annual pass available; enquire about educational group rates. About one-half mile hike to beach. Choptank Formation, moderate variety of invertebrates and shark teeth. Cliffs covered by vegetation; natural history enthusiasts will enjoy trails. Limited admission policy from late fall to early spring. Phone: (301) 535-5327; 586-1477.

4. Calvert Cliffs State Park, Calvert County, Maryland. Maryland Routes 2 and 4 to sign for "Calvert Cliffs State Park" (east). Free admission, hours vary with the seasons. Choptank Formation (two mile hike to beach); fossils are limited in numbers and kinds. Group camping area (closer to beach) available by prior arrangement. Phone: (301) 888-1622.

5. Chancellors Point Nature Center, St Marys City, St Marys County, Maryland. South on Maryland Route 5, west on Rosecroft Road to sign for "Chancellors Point Nature Center." Admission fee (includes admission to entire historic St Marys City, first colonial capitol of Maryland). St Marys Formation, excellent for mollusks, poor for vertebrates. Fossil collectors should seek permission in advance, with the understanding they will be required to present unusual finds (usually vertebrates) to the Nature Center. Phone: (301) 862-9891.

EXHIBITS

Calvert Marine Museum, P.O. Box 97, Solomons, Calvert County, Maryland 20688. Maryland Route 2, Solomons, Maryland. Includes large display of Calvert Cliffs fossils, and diagrams of regional geology; hands-on display in Discovery Room; and books and posters about fossils in Museum Store.

Free admission to main building at this writing. Special tours and educational activities available to groups through Education Department (a fee may apply).

Phone: (301) 326-2042.

SPACE FOR NOTES

SELECTED REFERENCES

Andrews, George W., 1988, A Revised Marine Diatom Zonation for Miocene Strata of the Southeastern United States. U. S. Geological Survey Professional Paper 1481, 29 pages, 8 plates. An expansion of Andrews' earlier diatom zonation of the Chesapeake Bay region to the entire Coastal Plain province.

Ashby, W. L., 1986, Fossils of Calvert Cliffs. Solomons, Maryland: Calvert Marine Museum, 20 pages, illustrated. Available from Calvert Marine Museum, P. O. Box 97, Solomons, Maryland 20588, $4.50 plus $1.00 postage. Good summary of geological and stratigraphic setting, with illustrations of representative vertebrates, most shark teeth, and a few invertebrates.

Clark, William B, G. B. Shattuck, and W. H. Dall (editors), 1904, The Miocene Deposits of Maryland: Maryland Geological Survey, 2 volumes. Baltimore: The Johns Hopkins University Press. Volume 1, Text (543 pages); Volume 2, Plates (135). This is the original major work, still available at used bookstores and in some local libraries. It has been reissued in paperback by the Maryland Geological Survey (Text, $5.00), (Plates, $6.00). Everything known about the Miocene of Maryland up to 1904, including bibliographies and illustrations of all species of fossils. Technical, somewhat out of date, but still the "bible" of collecting in the Maryland Miocene.

Donohue, M. D., and N. S. Gordon, 1967, Fossil Finds in Maryland: A Retrospective Bibliography. College Park, Maryland: The University of Maryland Libraries. The literature on fossils of the Maryland Miocene is widely scattered - this bibliography is particularly useful for updating the interval since the 1904 Maryland Geological Survey report (above).

Gernant, Robert E., 1970, Paleoecology of the Choptank Formation (Miocene) of Maryland and Virginia: Maryland Geological Survey, Report of Investigations number 12, 90 pages, illustrated. One of the first studies of the Choptank Formation to use modern paleontological methods. Out of print.

Gernant, Robert E., Thomas E. Gibson, and Frank C. Whitmore, Jr., 1971, Environmental History of Maryland Miocene: Maryland Geological Survey, Guidebook number 3, 58 pages, illustrated. A broader application of Gernant's 1970 paper (preceding) to provide an environmental interpretation for the entire Maryland Miocene. Paper: $2.50.

Glaser, John D., 1979 (Revised in 1986), Collecting Fossils in Maryland. Baltimore: Maryland Geological Survey, 76 pages, 49 figures. Paper: $1.00. Introduction to the classification of fossil plants and animals using Maryland specimens; maps to fossil localities (obtain permission before collecting); and a good bibliography.

McLennan, J. D., 1971, Miocene Shark's Teeth of Calvert County: Maryland Geological Survey. Free.

_____ 1973, Calvert Cliffs, Maryland: Maryland Geological Survey. Free.

Newell, Wayne L., and Eugene K. Rader, 1982, Tectonic Control of Cyclic Sedimentation in the Chesapeake Group of Virginia and Maryland, in Central Appalachian Geology, NE-SE GSA '82 Field Trip Guidebooks (P. T. Lyttle, Ed.), pages 1-29. Alexandria, Virginia: American Geological Institute.

Schoonover, Lois M., 1941, A Stratigraphic Study of the Mollusks of the Calvert and Choptank Formations of Southern Maryland. Bulletins of American Paleontology, Volume 25, number 94 B, pages 3-134, 12 plates. Although the Maryland Miocene report of 1904 cited the occurrence of all described species by formation, it gave no clue as to which part of the formation was meant. Schoonover's paper was the first attempt to be more specific, and it gives particular emphasis to the distribution and stratigraphic relationships of the pelecypods.

Vokes, Harold E., 1957, Miocene Fossils of Maryland: Maryland Geological Survey, Bulletin 20, 85 pages, 31 plates. This is an abbreviated and updated version of the Maryland Miocene volume of 1904. The most common invertebrate fossils are illustrated. Reprinted in paper, 1973: $1.50.

Ward, Lauck W., and Norman L. Gilinsky, 1988, Ecphora (Gastropoda: Muricidae) from the Chesapeake Group of Maryland and Virginia. Notulae Naturae, number 469, pages 1-21, 5 plates.

Ward, Lauck W., and Blake W. Blackwelder, 1975, Chesapecten, A New Genus of Pectinidae (Mollusca: Bivalvia) from the Miocene and Pliocene of Eastern North America: U. S. Geological Survey Professional Paper 861, 21 pages, 7 plates. This is a study of some of the most well-known Miocene fossils in Maryland. It includes a historical sketch of the earliest described fossil from the New World.

_____ 1980, Stratigraphic Revision of upper Miocene and lower Pliocene Beds of the Chesapeake Group - Middle Atlantic Coastal Plain. U. S. Geological Survey Bulletin 1482-D, 61 pages, 5 plates.

Publications of the Maryland Geological Survey can be ordered directly from:

Maryland Geological Survey
2300 St. Paul Street
Baltimore, Maryland 21218

Phone: (301) 554-5500

Maryland residents add 5 per cent sales tax. Many of these publications also may be in large public or reference libraries.

Trip 3

Northern Virginia's Mesozoic Rift Basin

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Introduction

Recent interest in the Mesozoic basins of eastern North America has led to increased knowledge in many fields of study, such as the stratigraphy, sedimentology, and tectonics of these basins (for example, Gore, 1983; Olsen, 1981, 1984; Smoot, 1985; Gottfried and Kotra, 1987) as well as rift basins in general. Much of this renewed interest results from new insights into the hydrocarbon potential of these rocks. However, even at this time, few wells or drillholes exist. Road cuts and quarries are still the major laboratories for study. A shallow core across the Newark basin in New Jersey by the Army Corp of Engineers is currently the focus of research by several workers at the U.S. Geological Survey. Cores also have recently been drilled in the Hartford basin (primarily through Jurassic only) and in the Gettysburg basin. For the Culpeper basin, however, outcrops and quarries still remain the main sources of information.

For those interested in the historical aspects and recent sedimentological advances of the eastern basins, the reader is referred to John Lorenz' eloquent book, Triassic-Jurassic Rift-Basin Sedimentology/History and Methods, published by Van Nostrand Rheinhold Company. Specific investigations of the Culpeper basin are given in the Additional References section.

Regional Geology

The Culpeper basin is part of the Newark Supergroup. The Newark Supergroup consists of several basins extending 2000

km along the eastern continental margin of North America (Fig. 1). Proponents of early tectonic models argued these basins to be grabens produced by extension normal to the basin axis. Recently, Manspeizer (1981) has suggested that many of these basins define tectonic structures that are associated with pull-apart basins formed within transcurrent fault zones and show evidence of strike-slip movement. He further suggests that most Newark-type basins are half-grabens along listric normal faults, which appear in many cases to be along reactivated thrusts. Such an interpretation of the origin of these basins should have a major influence on the amount and rate of sedimentation, and the hydrological conditions (type of fluvial drainage, open vs. closed basins, etc.), and thus on the diagenesis of accumulating sediments.

The sedimentary facies found in these basins vary from fluviatile and alluvial fan to lacustrine sequences. These include:

(1) A marginal border fault facies consisting of coarse, pebbly conglomerates representing alluvial fan and fan delta complexes, often interbedded with lacustrine gray to black siltstones and shales (Manspeizer, 1981);

(2) A marginal piedmont facies consisting of fluvio-deltaic sandstones and conglomerates (red beds), often interbedded with lacustrine deposits (Hubert and Reed, 1978);

(3) Central basin facies of lacustrine black-gray, finely

laminated shale and siltstone with coal, fish, and other fossils. A playa-type subfacies of red mudstones with evaporites, eolian sand, and calcrete is found in many of these basins (Manspeizer, 1981); The distribution of the major facies is given in Figs. 2A and 2B.

In the prevalent sedimentological model (Olsen, 1984), these sequences were deposited under terrestial conditions by rivers flowing from the border faults to the valley floor (alluvial-fan deposition). The finer sediments were deposited in stream-channel or flood-plain environments. Where lakes occupied the valley floors, lacustrine units were deposited. The prevailing paleoclimate determined the lake depths and therefore strongly influenced the weathering chemistry of the sediments.

Culpeper Basin

The Culpeper basin in Northern Virginia is a north-northeast-trending, faulted through at the inner margin of the Piedmont geologic province and adjacent to the eastern front of the Blue Ridge geologic province. The basin extends from northwest of the town of Orange, Virginia, northeastward to the Potomac River, and into Maryland, where it ends just southwest of Frederick, Maryland.

Clastic rocks ranging in age from Late Triassic to Early Jurassic (Cornet, 1977) are the major rock types found in the basin. The Triassic strata represent, for the most part, red sandstones and siltstones, with minor conglomerate, generally interpreted as alluvial-fan to fluvial deposits. The Jurassic sequences--while also containing redbeds--also contain coarse

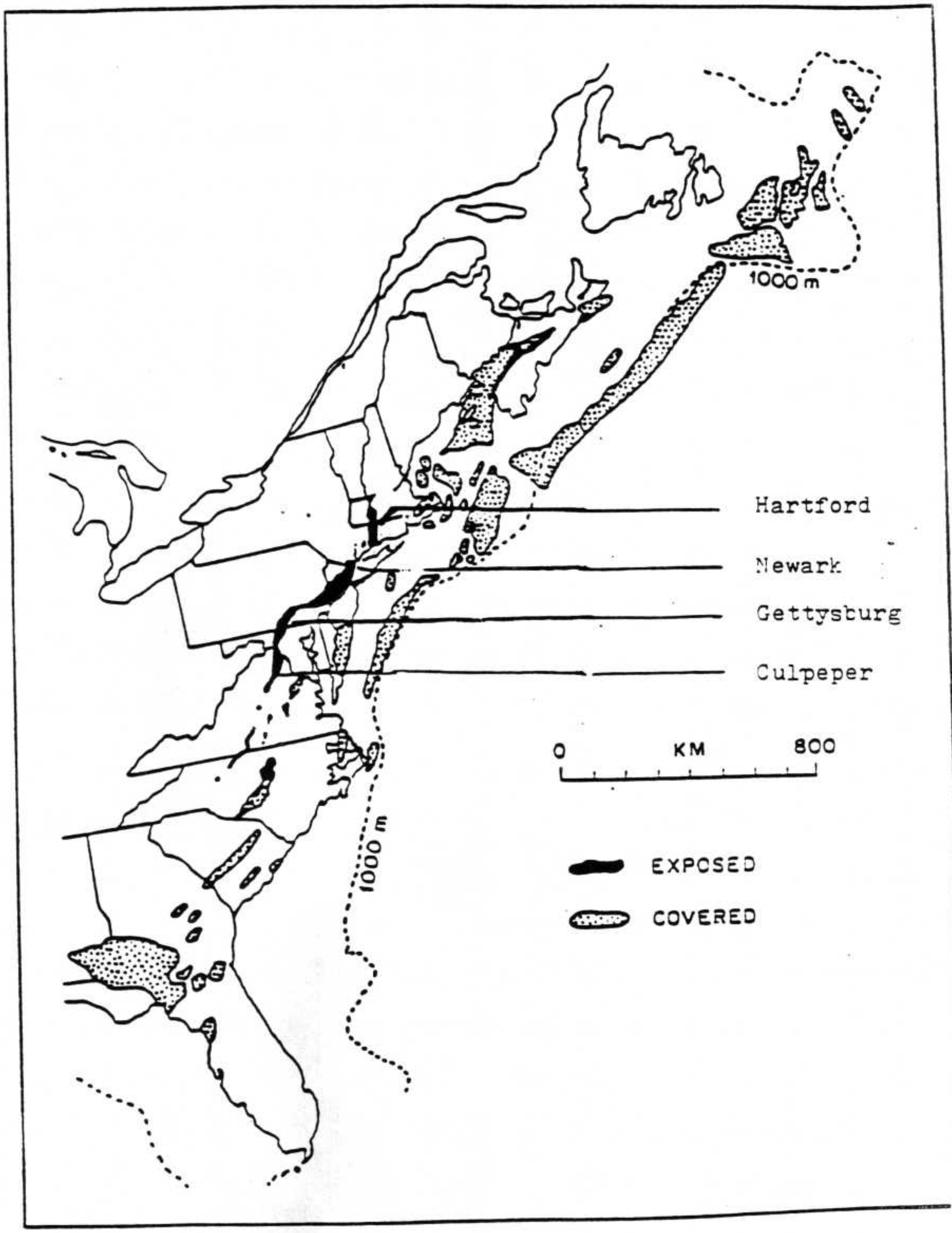


Fig. 1 Basins of the Newark Supergroup along eastern North America. (Van Houten, 1977)

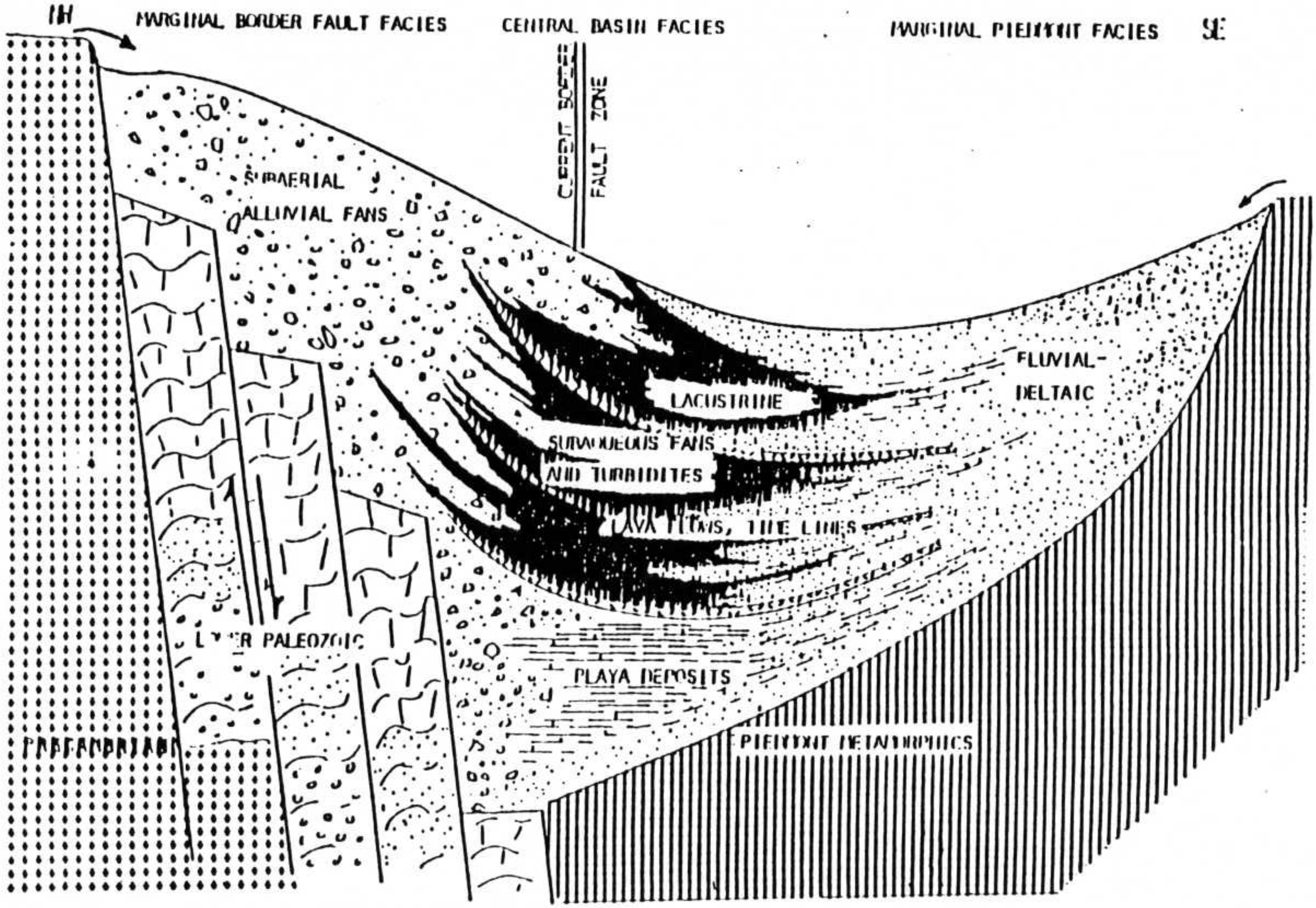


Fig. 2A Fan-delta sequence illustrating the distribution of facies in Newark-type rift basins.
(Manspeizer, 1981)

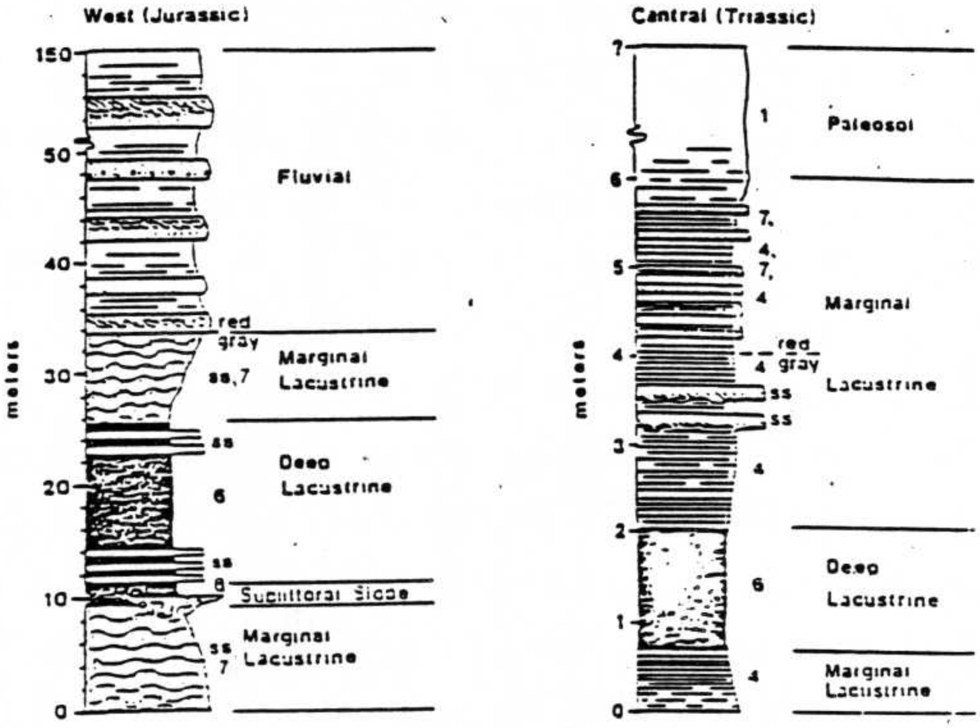


Figure 23 Typical columns through central basin facies (Olsen, 1984)

conglomerates (Smoot, 1985), intercalcated basalt flows, and cyclic gray and block shales interpreted as lacustrine facies. Diabase intrusions of Jurassic age can be found locally throughout the basin.

The rocks of the Culpeper basin dip generally westward toward a system of high-angle normal faults that forms the western margin of the basin. Dips tend to increase toward the west.

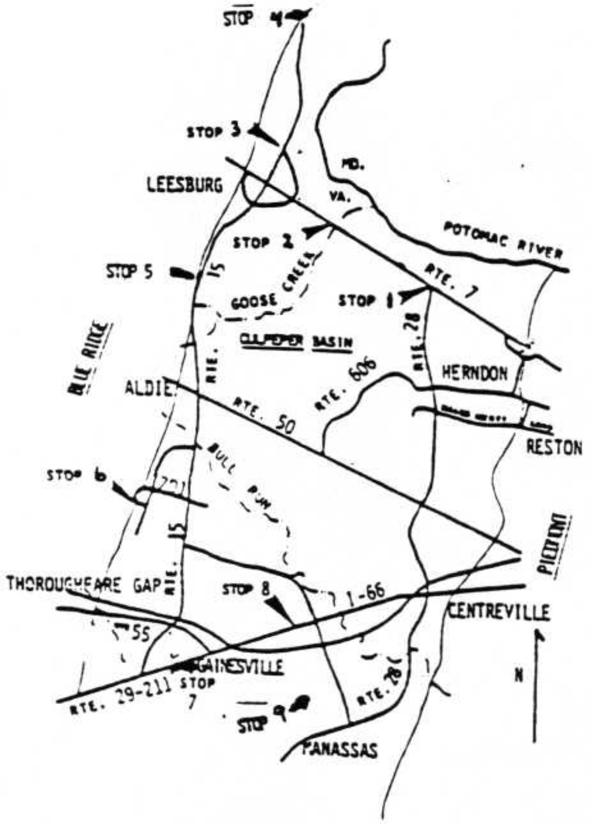


Fig. 2C Map of northern Culpeper basin, Virginia, showing location of stops.

Road Log

Description	Point-to-Point Mileage	Cumulative Mileage
Mileage begins at Dulles Toll Rd. and Rte. 7	0.0	0.0
Sugarland Rd. on left (crossing eastern border of the basin)	4.8	4.8
Dranesville Tavern on left	0.6	5.4
Campus of Northern Virginia Community College on right	4.8	10.2
Stop 1	2.1	12.3
Continue west on Rte. 7.		
Broad Run	0.2	12.5
The long ridge to the right is a northwest-trending extension of the diabase dike seen at Stop 1.	0.9	13.4
Xerox Training Center to the right its entrance marked by large exposures of diabase. This training center provides training for Xerox personnel from the U.S. and Canada.	3.2	16.6
Stop 2	0.9	17.5
Continue west on Rte. 7		
Federal Aviation Administration control center on left. The region's airborne traffic is monitored here.	1.7	19.2
Exit for U.S. Rte. 15 North bypass	0.1	19.3
Stop 3	4.7	24.0
Continue north on Rte. 15		
Exposure on right shows some well-developed inter-fingering of the carbonate clast conglomerate and the Balls Bluff siltstone.	3.7	27.7
Stop 4	3.5	31.2

Description	Point-to-Point Mileage	Cumulative Mileage
Retrace Rte. 15 back across Rte. 7 heading south		
For the next few miles, we are riding on the western margin of the basin, separating two physiographic provinces. Quartzite mylonite and Catoctin metabasalt are to the right. The road is actually just west of the border fault, so you can easily see the difference in the basin topography on the left, and the Blue Ridge to the right.	9.7	40.9
Low ridge to the left is formed on the oldest of the Jurassic basalt flows in the Culpeper basin.	3.0	43.9
Stop 5 - lunch stop (Oatlands)	5.1	49.0
Goose Creek. Jurassic basalt here is offset along a NE-trending fault.	0.2	49.2
Oak Hill on right. Oak Hill was built in 1818 from a design created for James Monroe by Thomas Jefferson. It contains many items used by President Monroe. Trees representing each state were gifts of congressmen. The famous "Monroe Doctrine" is said to have been written here. Jurassic dinosaur footprints may be seen in the patio stones of the formal gardens.	3.4	52.6
Gilbert's Corner. Aldie and Middleburg are to the west.	1.9	54.5
Junction with Rte. 701. Turn right.	4.6	59.1
Cross second Jurassic basalt, marked by low ridge.	0.1	59.2

Description	Point-to-Point Mileage	Cumulative Mileage
Cross another ridge formed by oldest flow of third Jurassic basalt	0.5	59.7
Junction with Youngs Drive turn left	1.2	60.9
Junction with Tiffany Lane. Turn left and park. Walk 300 m uphill for stop 6		
Stop 6	0.6	61.5
Return to Rte. 15. Turn right.	2.4	63.9
Continue until junction of U.S. Rte. 29-211, turn left onto 29-211.	5.5	69.4
Jurassic basalts outcrop on both sides of the road.	0.5	69.9
Pull off on shoulder on U.S. 29-211 just before railroad tracks for stop 7.		
Stop 7	2.0	71.9
Continue east on Rte. 15 Enter Manassas Battlefield Park on left. This park marks the site of the first major battle of the Civil War (First Manassas or First Bull Run) which occurred on July 21, 1861. Over 3,500 were killed or wounded in this first skirmish, which resulted in a Southern victory. Stop 8.		
Stop 8	7.8	79.7
Return west on U.S. 29-211, cross under U.S. 66 and turn left at Rte. 674	2.8	82.5

Description	Point-to-Point Mileage	Cumulative Mileage
Continue on Rte. 674. Turn left on Vulcan Road at enter Vulcan Quarry, stop 9.		
<u>Stop 9</u>	7.2	89.7
Return on Rte. 674 to U.S. 29-211. Turn right.	7.2	96.9
Enter U.S. 66 east and return to hotel.	0.4	97.3

STOP 1 <u>Metamorphic aureole around diabase (Rte. 7 - Rte. 28)</u>

Outcrops of thermally metamorphosed red mudstone and thin-bedded siltstone are exposed at this stop. These rocks are part of the "baked zone" that was produced by contact metamorphism during the intrusion of diabase. A fine-grained, non-foliated, non-schistose metamorphic rock resulting from contact metamorphism is called hornfels. The greyish color/cast of the hornfels is caused by thermal metamorphism. Epidote nodules found in these rocks were probably produced by metamorphism of calcite. Although the hornfels is generally massive, bedding and mudcracks have been preserved. At this location, the diabase is dark-grey, medium-to-coarsely crystalline, with a texture that is non-uniform and granular. Diabase dikes and sills are common features in the Culpeper basin and in other Mesozoic basins in Eastern North America. The dikes are thought to have formed as part of the igneous activity that accompanied the initial stages of rifting of the North Atlantic ocean during Triassic-early Jurassic time (c. 190 million years ago).

The metamorphic aureole surrounding diabase in the Culpeper basin comprises grey to dark-grey, medium-bluish-grey, and olive-black hornfels, granulite, and quartzite, derived from feldspathic, micaceous, ferruginous, and calcareous sandstone, siltstone, and minor shale. Light-grey and grey marble are also present, formed from metamorphosed carbonate clast conglomerate. Hornfels derived from argillaceous rocks contain three more or less distinct zones in the contact aureole: an inner zone of biotite, plagioclase,

titanite, and quartz; a middle zone of cordierite, andalusite, plagioclase, and quartz, or of abundant black tourmaline, plagioclase, and quartz; and an outer zone of chlorite, epidote, quartz, and (rarely) recrystallized feldspar. Granulite and quartzite form lenses, bands, and irregular masses. Marble consists of calcite, lime-garnet, diopside, and serpentine, associated with minor amounts of vesuvianite, magnetite, and wollanstonite.

Catlett clayey silt loams are present over baked or altered sedimentary rocks where surface soils are undisturbed. These soils are not fertile, and are difficult to farm. Runoff in these thin soils is rapid; they have a low water-holding capacity, and are generally a poor site for septic-tank drain fields.

Idell-Mecklenburg soils form on weathered diabase. Generally, these soils have moderate to rapid runoff, slow internal drainage, and commonly a montmorillonite-rich clay pan in the subsoil. This clay is generally underlain by a brownish saprolite that is sandy at its base, and contains spheroids of diabase. Such soils are not very desirable for farming and are generally poorly suited for septic tanks. Water wells in diabase generally yield small amounts of poor-to-fair-quality water, but a few high-yield wells have been completed in large open fractures.

STOP 2 Pyroclastics or Baked Red Beds

This area has been mapped by Toewe (1966). He concluded that these rocks were similar to pyroclastic rocks studied nearby, and interpreted the exposure to be andesitic or trachytic crystal tuffs with subordinate dacitic and basaltic crystal tuffs and thin basalt flows.

More recently, Lee (1978) has mapped this zone as a contact aureole of baked red beds in contact with the nearly Belmont Stock to the southwest. Further, the rocks at this stop are composed mainly of quartz, diopside, plagioclase, hornblende, and epidote. This assemblage of minerals is characteristic of metamorphosed calcareous argillaceous rocks, but not of pyroclastic rocks. Also, black and grey hornfels commonly forms belts which surround many of the larger intrusive bodies in the Culpeper basin.

A normal fault with a gouge zone is also present. Numerous slickenslides may be found with epidote and other mineralization in these zones. Some copper mineralization produced by hydrothermal alteration also occurs.

STOP 3 Carbonate clast conglomerate (Balls Bluff Nat'l. Cemetery)

The conglomerate present at this stop is part of a thick conglomerate sequence that extends from Leesburg northward to Frederick, Maryland. It is interbedded with red fine-grained sandstone and silty mudstone. The conglomerate is typically massive, lacking erosional surfaces, sedimentary structures, and clast orientation. Clasts are mostly limestone, with subordinate amounts of dolomite, quartzite, and assorted rock fragments. The clasts range in size from pebbles to cobbles and (locally) boulders. An increase in clast size from east to west, and west to east paleocurrent directions indicates that the source area was to the west. The matrix-supported conglomerates and the associated mudstones and sandstones were deposited as debris flows and mud flows on alluvial fans which spread eastward from the elevated, fault-bounded western margin of the Culpeper basin. These rocks are Triassic age (240-205 m.y.).

This area has characteristics similar to those of karst terrains. For example, many perennial springs discharge large volumes of hard water, the region has numerous ponds and poorly drained sink holes, and a few large overhanging caves are known. Furthermore, large water-filled cavities have been encountered during drilling for ground water. Since its origin in 1750, the town of Leesburg has depended for its water supply on springs or on high-yield water wells completed in cavities in the limestone conglomerate.

STOP 4 <u>Weverton Formation (Rte. 15 N)</u>

The contact between the western edge of the basin and the Blue Ridge can be seen here. The Weverton Formation is a light-gray, vitreous, fine-grained, finely-laminated or banded quartzite. It was originally a mature quartz sandstone deposited by the transgression of the Proto-Atlantic ocean shortly after this ocean basin formed. The sandstone was metamorphosed in Ordovician time (Taconic Orogeny). Only the basal beds of the Weverton are present at the surface; a greater thickness was probably downfaulted into the Culpeper basin and covered by Triassic sedimentary rocks.

STOP 5 Oatlands House

Oatlands, a Classical Revival mansion that was once the center of a thriving 3,400-acre plantation, is located in the heart of Northern Virginia's hunt country. A gazebo and terraced formal gardens were planned by Oatlands' builder, George Carter, a great-grandson of famed planter Robert "King" Carter. Oatlands, constructed shortly after 1800, was partly remodeled in 1827. A front portico with hand-carved Corinthian capitals was added later. Confederate troops were billeted in the house during the Civil War. The garden in the back of the house contains Jurassic dinosaur footprints believed to belong to *Anchiosaurus* and a larger, unidentified carnivore.

STOP 6 Border conglomerate (Tiffany Lane, east flank of Bull Run Mtn.)

Saprolitized (highly weathered) conglomerate of Jurassic age crops out immediately adjacent to the steeply eastward-dipping normal fault which forms the western margin of the Culpeper basin. The conglomerate contains clasts of several different lithologies, including quartzite, phyllite, and greenstone. A ridge of micaceous quartzite with interbedded phyllite crops out along the top of Bull Run Mountain. This foliated, banded quartzite is part of the Weverton Formation (Cambrian age, 570-500 m.y.). The presence of staurolite in the quartzite indicates that regional metamorphism reached amphibolite facies conditions.

STOP 7 Jurassic basalt (Rte. 15)

The lower contact between a flow of lower Jurassic basalt and underlying red silty sandstone and sandy siltstone is exposed at this stop. This is the oldest of a series of basalt flows interbedded with fluvial red beds and grey lacustrine strata. Based on palynological age dating of nearby beds (Cornet, 1977), this basalt is close to the Upper Triassic-Lower Jurassic contact. The basalt is a high-TiO_2 quartz-nomative tholeiite, one of the ENA types of Weigand and Ragland (1970). Joints, particularly sub-columnar cooling joints, are abandant. Both the basalt and the red beds are highly altered across a narrow zone at the base of the flow.

Basalt in the Culpeper basin commonly does not weather deeply, but produces thin, poorly drained soils (Montalto silt loam and silty clay loams). Usually intensely jointed and sheeted, the basalt commonly breaks into fragments 10-20 cm across by readily splitting along intersecting fractures. It is quarried for use as crushed stone, aggregate, road metal, fill, subbase, and rip-rap.

STOP 8 <u>Upper Triassic lacustrine sequence (Manassass Battlefield Park)</u>

The olive-grey beds exposed in this outcrop are typical of thin strata within the Upper Triassic section, which is dominantly composed of reddish-brown mudstones and siltstones (redbeds). This section contains four main lithologies which are distinguished by grain size, bedding style, and fossil content.

Lithology A is dark-reddish-brown massive mudstone and poorly laminated shale with scattered calcite granules and stringers. Its generally massive character may have been caused by bioturbation. Lithology B consists of olive-grey to light-olive-grey, poorly laminated shale, and includes a thin (10 cm) bed of dark-grey, calcareous shale. Lithology C is olive-grey to light-olive-grey, crossbedded calcareous sandstone. Several beds show evidence of soft sediment deformation; for example, calcareous "sand nodules" probably formed by sand beds breaking apart as they collapsed into the underlying mud. Lithology D is composed of greyish red, well-laminated shale interbedded with thin (2-3 cm) beds of blackish-red siltstone which is calcareous, fossiliferous and may contain mudcracks.

Lithology A forms the basal portion of the sequence at Stop 8. Its red color, possible bioturbation, absence of fossils, and presence of calcite granules and stringers (caliche?) suggest that lithology A was deposited in an environment characterized by intermittent flooding and subaerial exposure.

These are overlain by interbedded olive-grey and greyish brown sequences of lithologies B and D, which were probably deposited near the shore of a perennial lake or in ephemeral lakes formed during the transgressive stage of a lacustrine sequence. Shallow (above-wave-base) conditions are indicated by crossbedding in the greyish-brown siltstone (lithology D). The middle portion of the sequence is non-fossiliferous light-olive-grey shale (lithology B), the thickest in the sequence. The crossbedded sandstone (lithology C) was deposited in shallow water near the lake shore during the regressive phase of the lacustrine sequence.

STOP 9 Vulcan Materials Quarry

The quarry is an excellent stop for gaining an appreciation of the field relationships of Mesozoic rocks. In addition, a variety of minerals associated with intrusion and hydrothermal processes can be found here.

It is possible at this quarry to see the contact between exposed diabase and shales. Hornfels is again visible in association with the intrusions. Mineralization associated with these rocks include apophyllite, prehnite, and calcite as vein fillings. The hornfels and diabase may contain vugs filled with a variety of zeolites, e.g., orange-colored stilbite (usually occurring as radiating crystal masses) and yellow-colored chabazite (rhombohedron habit). Aplite dikes are also exposed in parts of the quarry.

The history and economics of the quarry are also quite interesting. The foreman will discuss these aspects of this site.

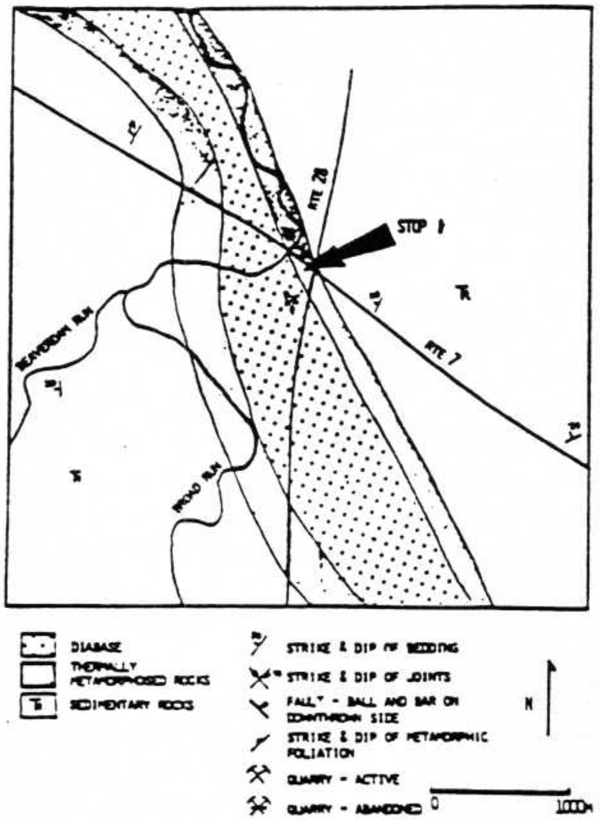
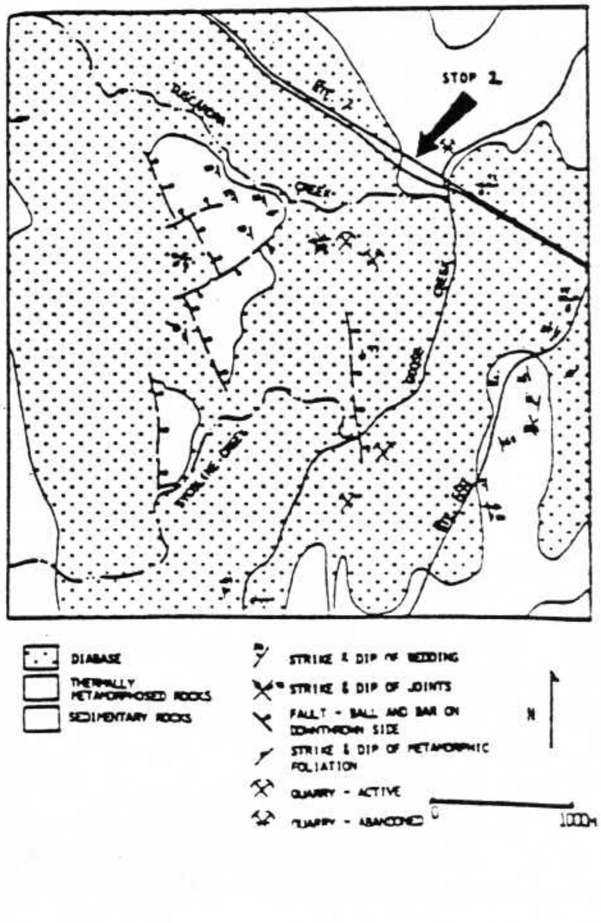


Figure 3. Geologic map of Stop 1 and vicinity. Geology modified from Froelich, et.al. (1982)

Figure 4. Geologic map of Stop 2 and vicinity. Geology modified from Froelich, et.al. (1982)



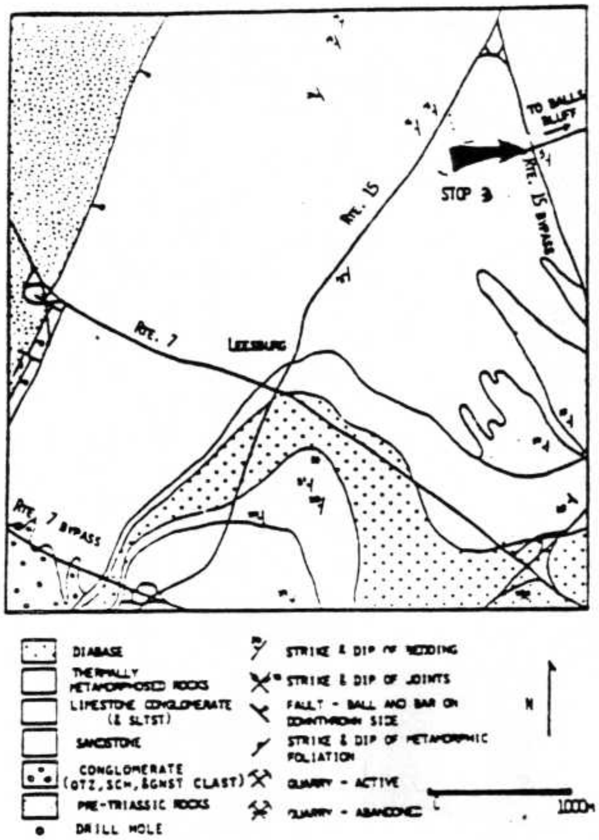


Figure 5. Geologic map of Stop 3 and vicinity. Geology modified from Froelich, et.al. (1982)

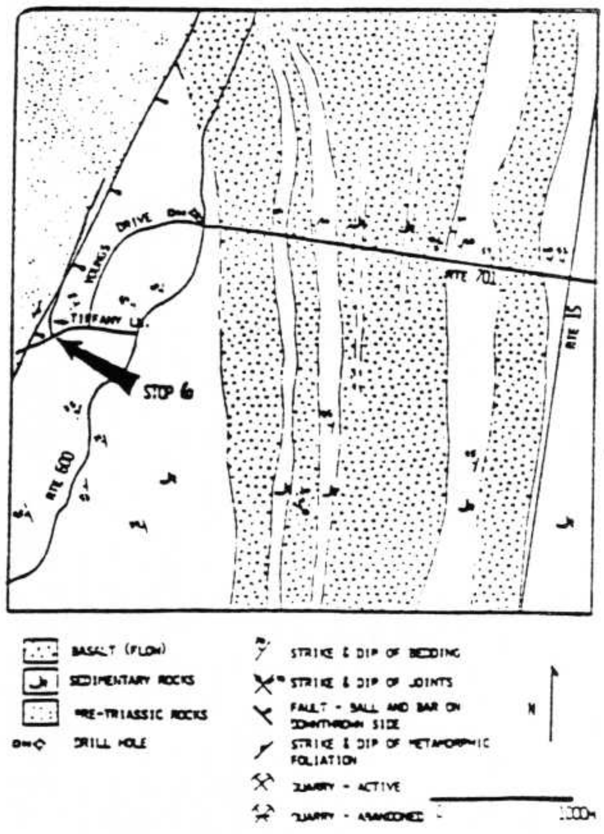


Figure 6. Geologic map of Stop 6 and vicinity. Geology modified from Froelich, et.al. (1982)

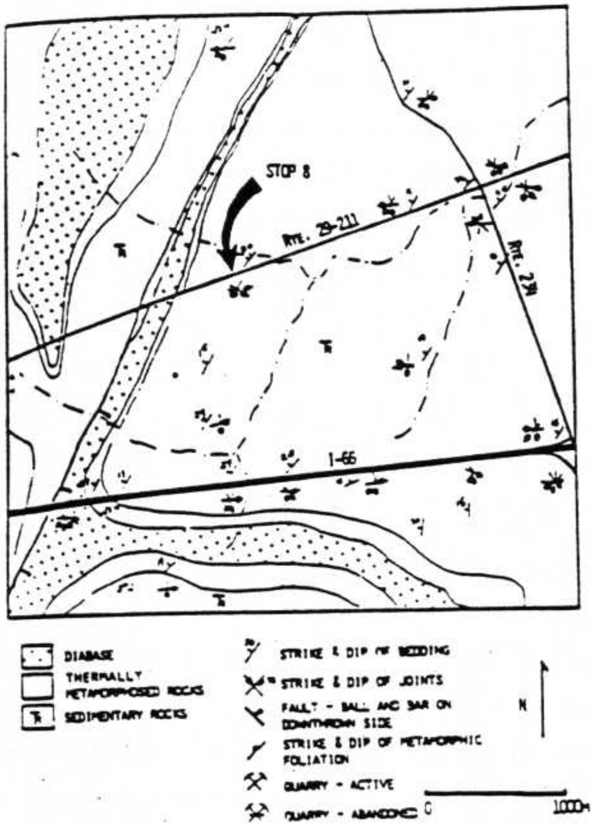


Figure 7. Geologic map of Stop 8 and vicinity. Geology modified from Froelich, et.al. (1982)

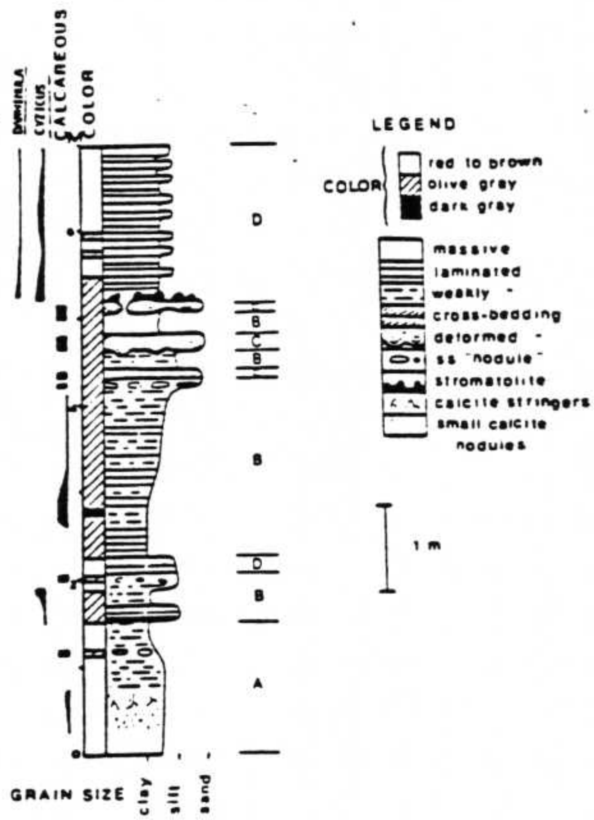


Figure 8. Lithology exposed at Stop 8. Section measured by Lindholm & Gore (1981).

Appendix 2 - Stratigraphic Nomenclature of Selected Mesozoic Basins* (U.S.G.S. 1988)

	Hartford Basin	Newark Basin	Gettysburg Basin	Culpeper Basin
Lower Jurassic	Portland Formation	Boonton Formation		Waterfall Formation
	Hampden Basalt	Hook Mountain Basalt		Saunder Basalt
	East Berlin Formation	Towaco Formation		Turkey Run Formation
	Holyoke Basalt	Preakness Basalt		Hickory Grove Basalt
	Shuttle Meadow Formation	Feltville Formation	Brunswick Formation	Midland Formation
	Talcott Basalt	Orange Mountain Basalt	Aspers Basalt	Mount Zion Church Basalt
Upper Triassic				Catharpin Creek Formation
		Passaic Formation		
	New Haven Arkose		Gettysburg Formation: Heidlersburg Member	Balls Bluff Siltstone
		Lockatong Formation		
		Stockton Formation	New Oxford Formation	Manassas Sandstone

* = Actual formation thicknesses are not shown in this table

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STRUCTURE AND HISTORICAL GEOLOGY OF THE APPALACHIANS
NEAR HANCOCK, MARYLAND

Barbara Levinson, EPA Washington, DC
Wallace White, Mt. Hebron High, Ellicott City, MD.

The rocks we are going to study today span most of the Paleozoic era from Silurian through Mississippian age. These rocks are interbedded sedimentary rocks consisting of sandstones, siltstones, shales, limestones, and coal that were deposited in ancient inland seas or deltas.

The activities today will include:

* identifying lithologies (rock types)
* describing depositional environments
* identifying folds and faults
* collecting and identifying fossils

General Precautions:

Some of the sites are along roads or highways. Be aware of where you are walking.

Please wear glasses or goggles when you are bashing the rocks. Be aware of colleagues who are not wearing eye protection.

For coffee drinkers: there may be many hours between pit stops.

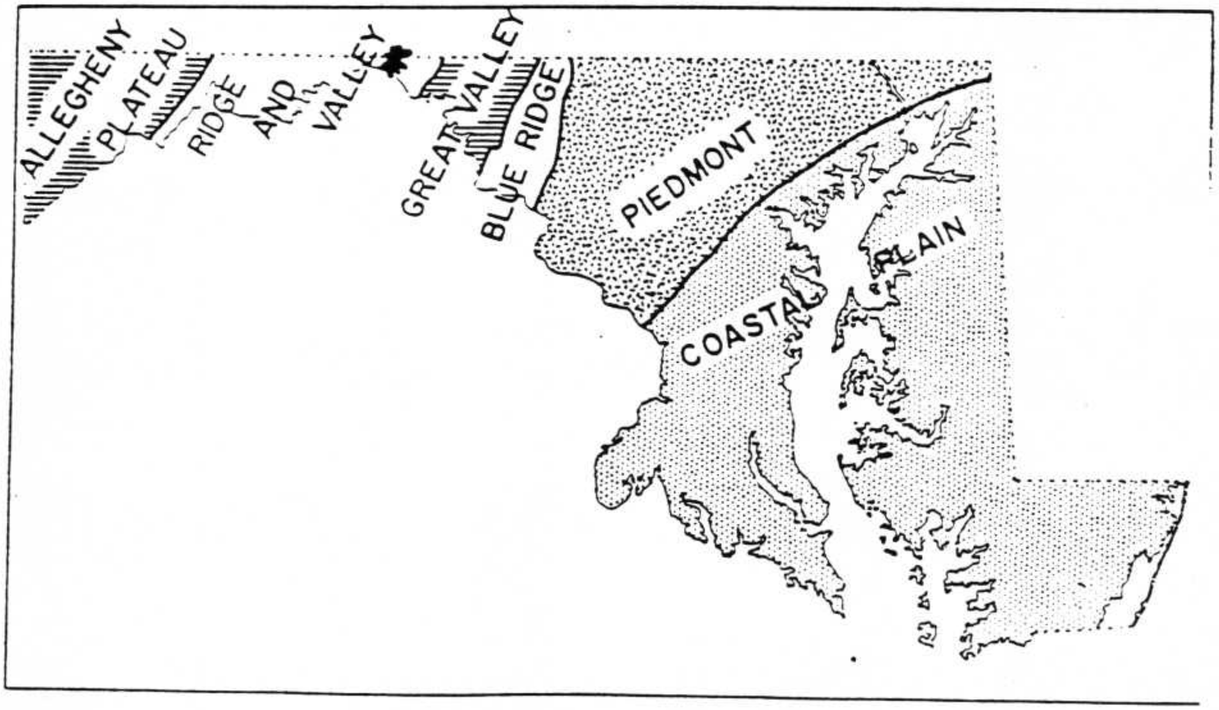

Figure 1. Physiographic provinces of Maryland

Geologic Eras	Periods	Epochs	Rock Terminology	History	
CENOZOIC ERA				Lake deposits and drainage changes due to glaciation to north	
MESOZOIC ERA	CRETACEOUS JURASSIC TRIASSIC			Igneous activity in Pendleton and surrounding counties	
PALEOZOIC ERA	PERMIAN		DUNKARD GROUP	Appalachian Orogeny. West Virginia was uplifted and become an erosion surface. For more than 200 million years it has never been invaded by the sea and no extensive sediments have been deposited.	
	PENNSYLVANIAN	LATE	MONONGAHELA GROUP CONEMAUGH GROUP		
		MIDDLE	ALLEGHENY FORMATION	Swamp conditions throughout most of the State resulted in the preservation of plant remains which were altered to peat and in turn altered to the many coal seams.	
		EARLY	POTTSVILLE GROUP: KANAWHA FM, NEW RIVER FM, POCAHONTAS FM.		
	MISSISSIPPIAN	LATE	MAUCH CHUNK GROUP	Nonmarine environment. Shale and sandstone predominate, red beds very predominant near top.	
		MIDDLE	GREENBRIER GROUP	Shallow sea once again covered most of West Virginia. Carbonate deposition predominates. Last important marine deposition in West Virginia.	
		EARLY	MACCRADY FORMATION POCONO GROUP	Uplift continued and a nonmarine environment existed. Sandy shales predominate.	
	DEVONIAN	LATE	HAMPSHIRE FORMATION CHEMUNG GROUP BRALLIER FORMATION	Shoreline gradually shifted westward, causing abundant continental beds which were deposited farther and farther westward throughout the epoch.	Acadian Orogeny with main uplift to northeast
		MIDDLE	HARRELL SHALE MAHANTANGO FORMATION MARCELLUS FORMATION	Uplift to east provides clastic sediments for marine dark shale with sandstone layers.	
			ONESQUETHAW STAGE: TIOGA BENTONITE	Volcanic activity to east results in thin bentonite zone.	
			ONESQUETHAW STAGE: ONONDAGA LIMESTONE / HUNTERSVILLE CHERT / NEEDMORE SHALE	Slight subsidence. Shale deposition predominant in northeast, chert in southeast, passing to cherty limestone in west.	
		EARLY	ORISKANY SANDSTONE	Sea somewhat shallower. Blanket sandstone deposition.	
			HELDERBERG GROUP	Slight submergence creates a predominantly carbonate-producing environment, but with invasions of sand and clay.	
	SILURIAN	CAYUGAN LATE	TONOLOWAY FORMATION (BLOOMSBURG FACIES)	Sea covered most of the State. Carbonates predominate in southwest. Evaporite deposition in restricted sea of northern West Virginia.	
			WILLS CREEK FORMATION (BLOOMSBURG FACIES)	Red delta deposits in northeastern West Virginia; marine shale and limestone to southwest.	
			WILLIAMSPORT FORMATION (BLOOMSBURG FACIES)	Red bed deposition continues in northeast; shallow sea sandstone deposition in rest of State.	
		NIAGARAN MIDDLE	MCKENZIE FORMATION (BLOOMSBURG FACIES)	Tidal flat in northeast marks beginning of red bed deposition. Shallow marine carbonates in southwest.	
			ROCHESTER SHALE KEEFER SANDSTONE ROSE HILL FORMATION	Predominantly a shallow marine environment with clastic deposition.	
		EARLY	TUSCARORA SANDSTONE	Shallow sea covered the State. Sandstone deposition.	
	ORDOVICIAN	LATE	JUNIATA FORMATION	Delta-type environment throughout State.	Taconic Orogeny formed an area of high mountains to the east, the source of most of the sediments of the Late Ordovician and Silurian.
			OSWEGO FORMATION	Delta-type environment in eastern West Virginia	
			REEDSVILLE SHALE / MARTINSBURG FM	Clastic deposition in marine environment	
		MIDDLE	TRENTON GROUP / NEALMONT LS BLACK RIVER GROUP	Carbonate deposition continues to predominate.	Volcanic activity caused deposition of bentonite beds.
			ST PAUL GROUP	Knox unconformity; predominant in Ohio and western West Virginia.	
		EARLY	KNOX: BEEKMANTOWN GROUP		
	CAMBRIAN	UPPER	KNOX: CONOCOCHEAGUE FM (EAST) / COPPER RIDGE DOL (WEST)	Carbonate deposition.	
		MIDDLE	ELBROOK FORMATION		
		LOWER	WAYNESBORO FORMATION	Clastic deposition	
			TOMSTOWN DOLOMITE	Shallow sea carbonate deposition	
			CHILHOWEE GROUP: ANTIETAM FM	First fossils in West Virginia rocks	
	Ante Camb	?	CHILHOWEE GROUP: HARPERS FM WEVERTON LOUDOUN FORMATION	Clastic deposition in narrow trough in eastern West Virginia, beginning of Appalachian Geosyncline.	
			CATOCTIN FORMATION	Volcanic activity in eastern West Virginia	
PRECAMBRIAN			CRYSTALLINE ROCKS	History complex and obscured	

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Figure 2. Generalized Stratigraphic Column

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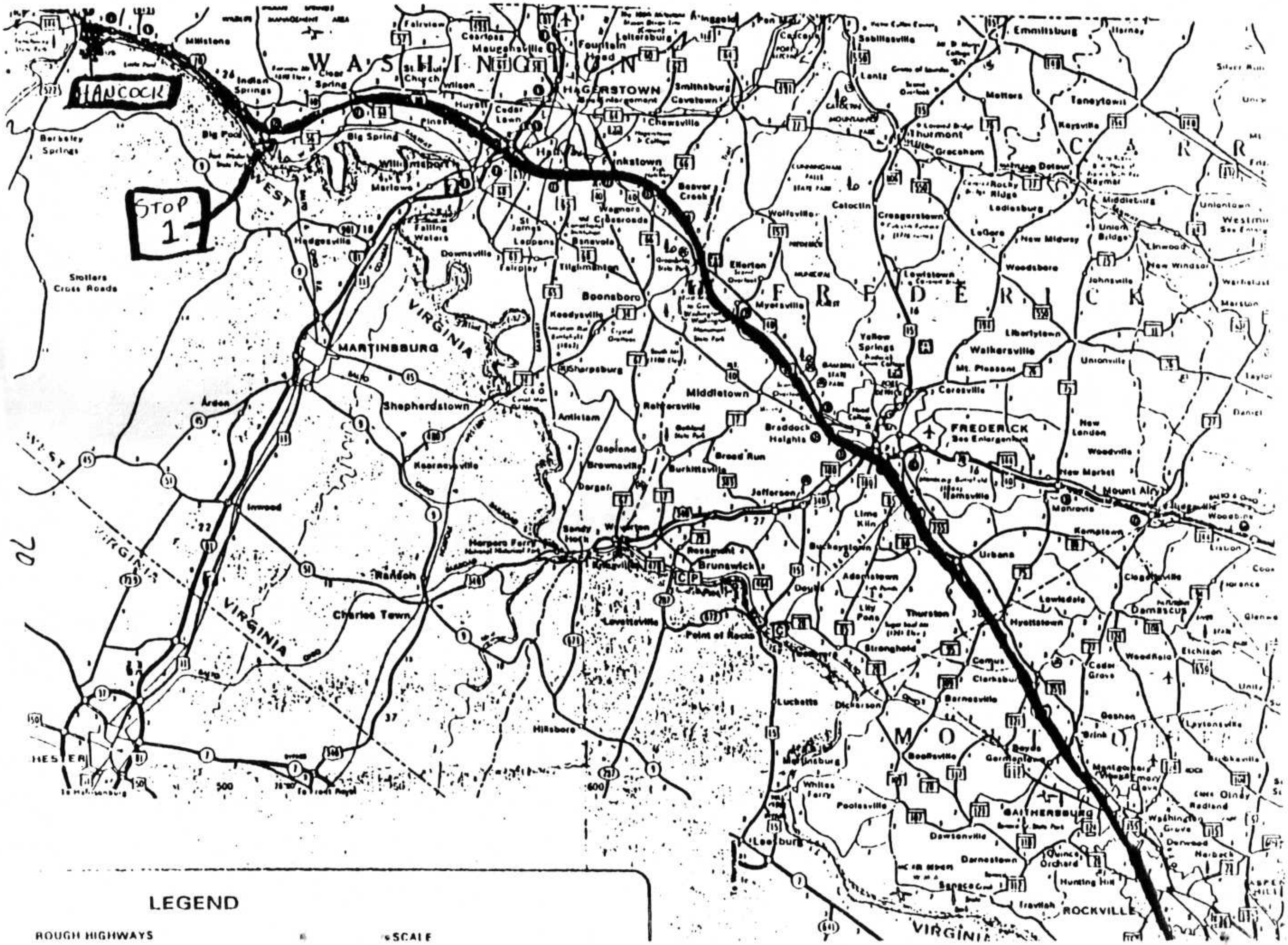
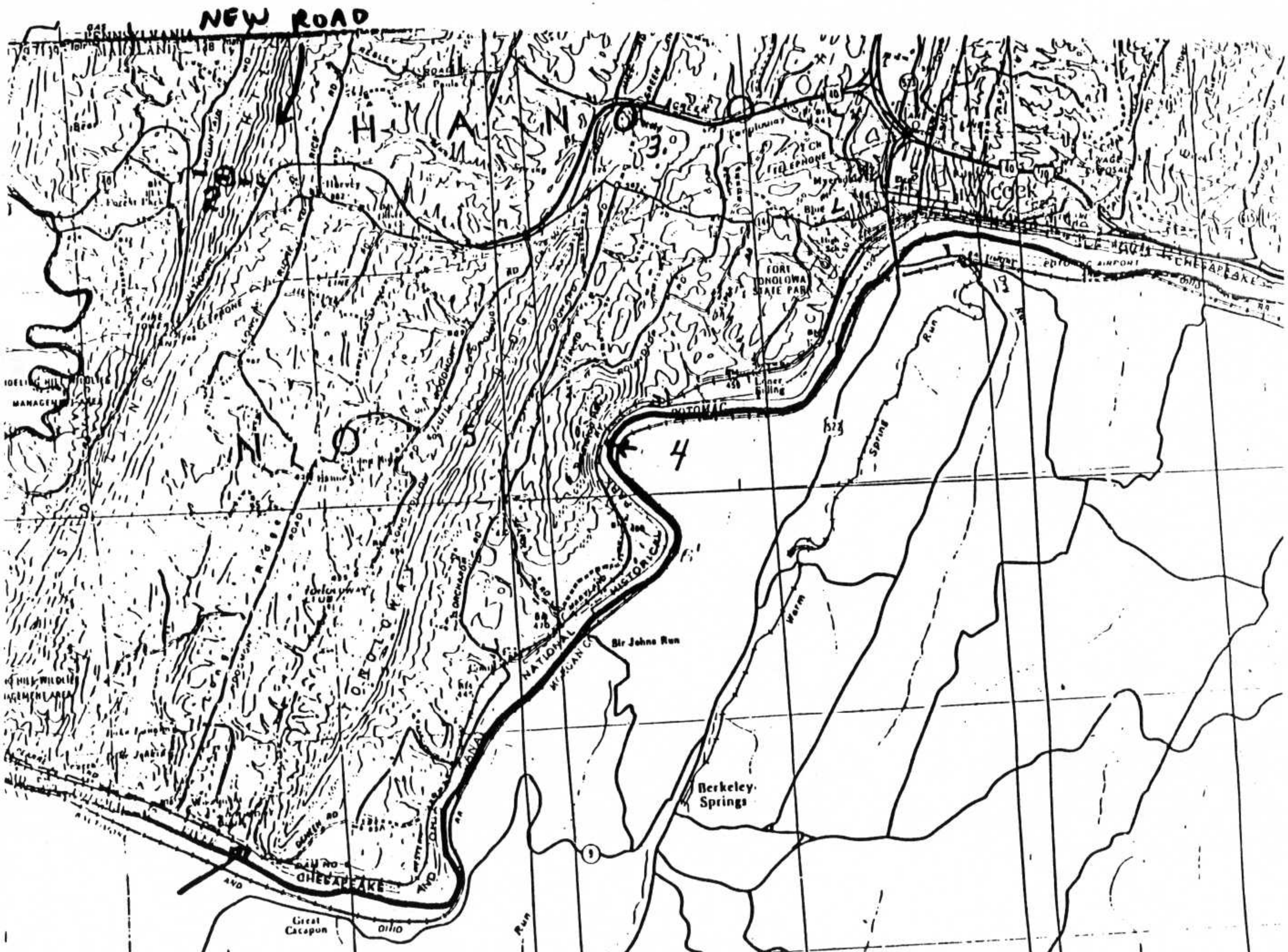

HANCOCK
STOP 1
WASHINGTON
HAGERSTOWN
FREDERICK
CARROLL
MONTGOMERY
WEST VIRGINIA
VIRGINIA
MARTINSBURG
Shepherdstown
Charles Town
Harpers Ferry
Brunswick
Boonsboro
Middletown
Emmitsburg
Thurmont
Williamsport
Berkeley Springs
Mount Airy
Urbana
Damascus
GAITHERSBURG
ROCKVILLE
Leesburg
LEGEND
ROUGH HIGHWAYS
SCALE

70



NEW ROAD
PENNSYLVANIA
MARYLAND
HANCOCK
TELEPHONE
FORT TONOLOWAY STATE PARK
CHESAPEAKE AND OHIO
POTOMAC
NATIONAL HISTORICAL PARK
4
3
7
Sir Johns Run
Warm Spring Run
Berkeley Springs
Great Cacapon
Run

72

From Washington Beltway I-495 take I-270 North to I-70 West (at Frederick, MD). Proceed to Rte. 56 South exit.

0.0 Exxon Station at I-70 and Rte 56.
1.2 Ft. Frederic Park
2.6 Metallic building on left.

Stop 1 Fossil Site

This is private property so make sure you ask permission to look for fossils. If the owners are not available, you may continue down Rte. 56 and turn right on McCoys Ferry Rd. Take the high road to the left at the railroad bridge and park in the area on the left. There are lots of fossils in the slope adjacent to the parking area.

This site is in the middle-Devonian Mahantango Fm.

Retrace your route up to I-70 and proceed west. At Hancock continue on Rte. 40/48 west to Sideling Hill about 22 miles. The bus will stop along the Interstate with the permission of the Highway Department (this is ordinarily illegal).

Stop 2 Sideling Hill

Sideling Hill is a syncline with rocks of Mississipian Age (350 my to 280 my ago). The rocks range from sandstones to siltstones to shales with interbedded coal seams. These formations represent an ancient delta with vast swamps. The rivers carrying sediments from the east built up the delta as they flowed west towards a shallow inland sea.

BE CAREFUL OF THE INTERSTATE

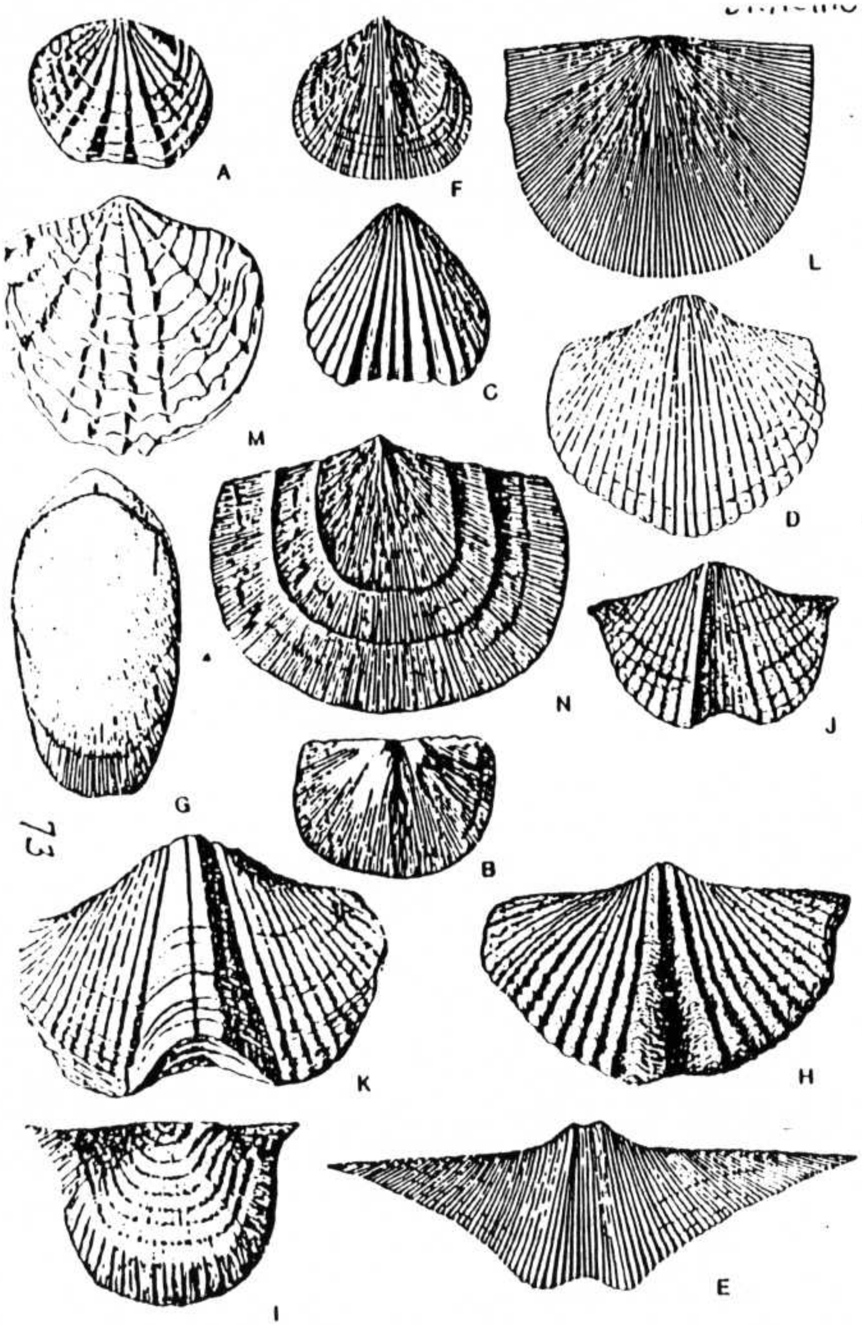


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Figure 3. Common Maryland brachiopods:
A. *Anoplotheca* (Silurian-Devonian)
B. *Chonetes* (Silurian-Devonian)
C. *Camarotoechia* (Silurian-Devonian)
D. *Costispirifer* (Silurian-Devonian)
E. *Cyrtospirifer* (Devonian)
F. *Dalmanella* (Silurian-Devonian)
G. *Rensselaeria* (Silurian-Devonian)
H. *Mucrospirifer* (Devonian)
I. *Leptaenea* (Silurian-Devonian)
J. *Spirifer* (Devonian)
K. *Spinocyrtia* (Devonian)
L. *Schuchertella* (Silurian-Devonian)
M. *Atrypa* (Silurian-Devonian)
N. *Orthotetes* (Mississippian)

Figure 4 *Solen*, a razor clam

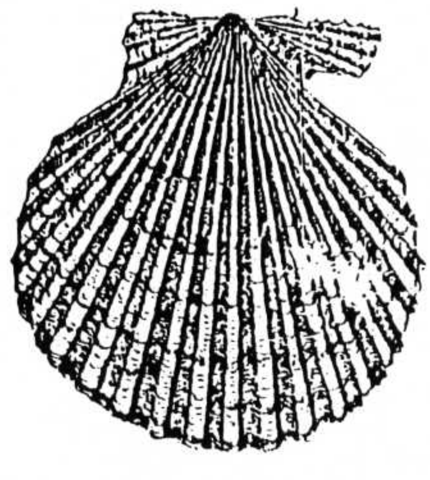


Figure 18. *Chlamys*, a representative modern scallop

GlASER, MGS Ed

COELENTERATA

(jellyfishes and corals)

Figure 5a *Hydractinia*, a Miocene encrusting hydrozoan

Figure 5b *Stromatopora* from the Upper Silurian-Lower Devonian Keyser Limestone

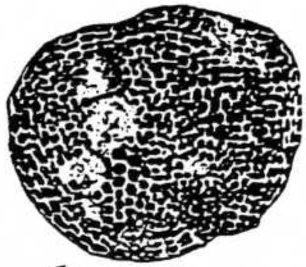


Figure 5c *Favosites* from the Devonian limestones of Western Maryland

Figure 5d *Zaphrentis*, a Devonian horn coral

BRYOZOA

(moss animals)

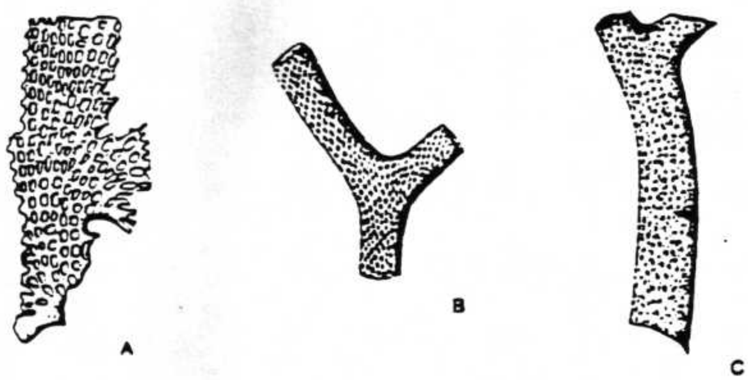


Figure 6 Paleozoic bryozoa: A. *Fenestella*; B. *Orthopora*; C. *Batostomella*

Glaser: MGS Ed.

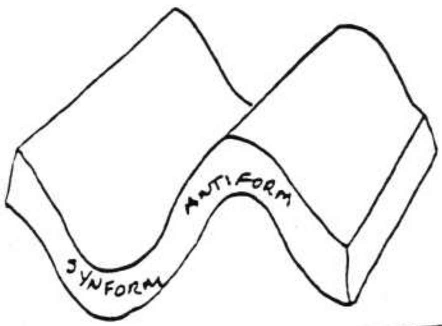
Definitions:

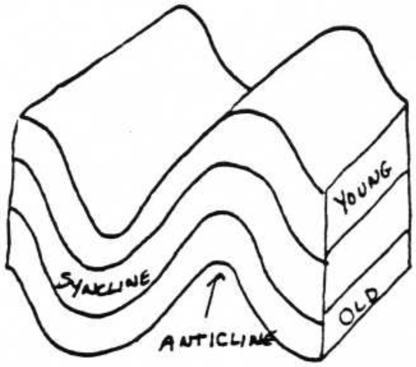
Synform: A fold that closes downward.

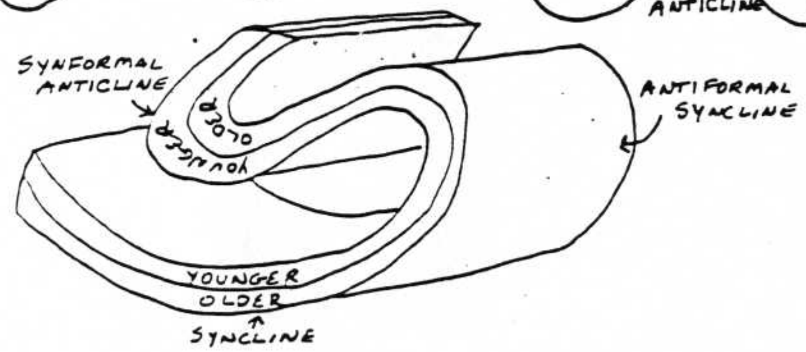
Antiform: A fold that closes upward.

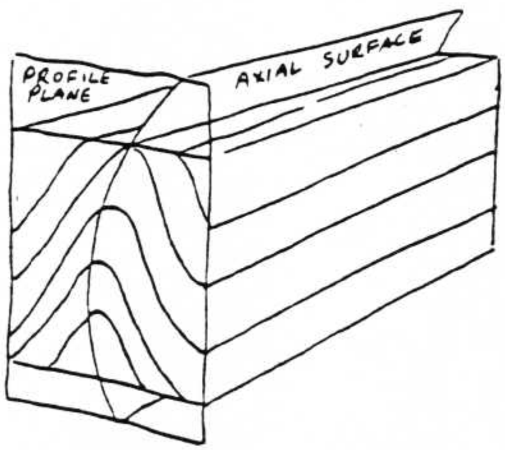
Syncline: A fold with younger rocks in its core.

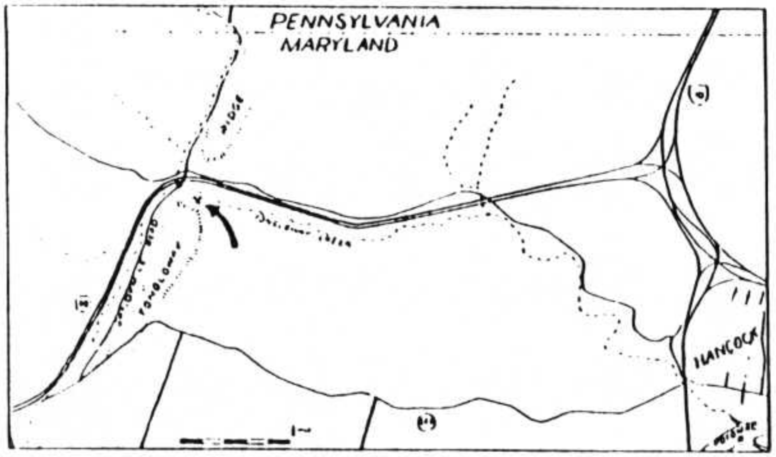
Anticline: A fold with older rocks in its core.











WASHINGTON COUNTY: Devonian fossil locality near Hancock.

An abandoned limestone quarry and an adjoining road cut near Hancock provide a fine locality for collecting Lower Devonian fossils. Two formations are exposed here. The bluish cherty limestone in the quarry belongs to the Helderberg Group whereas the soft white sandstone in the high cut at the quarry entrance is the Ridgeley Sandstone. Both the quarry and the cut can easily be seen from U.S. 40, just south of the highway at the point where it cuts through Tonoloway Ridge, 2.2 miles west of the I-70 interchange. However, the locality must be reached via Sandy Mile Road from Md. 144 which intersects with U.S. 40 about one mile further west. From Sandy Mile Road, a short entrance road leads east into the quarry just south of the U.S. 40 overpass.

Collecting in the quarry, especially among the weathered blocks and the talus heaps, will turn up numerous brachiopods as well as bryozoans and corals. More careful searching may reward the collector with a cluster of the curious conical pteropod *Tentaculites*, often arrayed in parallel fashion on the rock surface by some ancient bottom current. Other finds might include fragments of trilobites and crinoids.

Fossils are also to be found in the white crumbly sandstone of the Ridgeley in the road cut. Here all of the specimens will be molds and casts, chiefly of brachiopods and gastropods. Conspicuous among the brachiopods are the large, coarsely-ribbed *Costispirifers* and *Acrospirifers*. Internal molds of *Platyceras*, a large Devonian snail, are also common. The piles of loose sand at the base of the cut have resulted from the solution of the calcite cement holding the sandstone together.

FOSSILS PRESENT: **Helderberg forms**

Brachiopods: *Dalmanella*
Rhipodomella
Leptaena
Stropheodonta
Strophonella
Schuchertella
Eospirifer
Meristella
Atrypa
Uncinulus

Pteropod: *Tentaculites*

Gastropod: *Platyceras*
Corals: *Favosites*
Cyathophyllum

Trilobite: *Phacops*

Bryozoan: *Orthopora*

Crinoid: columnals

Ridgeley forms

Brachiopods: *Costispirifer*
Acrospirifer
Rhipidomella
Leptostrophia
Rensselaeria
Anoplotheca
Meristella
Camarotoechia

Gastropod: *Platyceras*

6/45

Stop 3: Abandoned Quarry

There are two rock types exposed at this site, the Oriskany sandstone and the Helderberg limestone.

1) The Oriskany sandstone is a pure quartz sandstone that is usually of a light gray to white color on fresh surfaces. The sand grains are held together with a calcareous cement.

The Oriskany is a ridge forming unit. The pure sands are quarried and washed for glass sand.

The Oriskany has yielded a large fauna. The fossils are unusually well preserved as molds and internal cores of sand. A distinctive feature of the fauna is the large size of the fossils.

2) The Helderberg Group is the lowermost strata of the Devonian system in the Appalachian trough. The Helderberg is primarily a fossiliferous limestone, although there are sandy or cherty sections.

Stop 4: Roundtop Railroad Cut, Hancock, MD.

McKenzie formation: The McKenzie fm. named from McKenzie Station on the Baltimore and Ohio Railroad, nine miles south of Cumberland, consists of interbedded gray shales and muddy limestones with some intercalated red shales and sandstones. The shales and limestones of the McKenzie fm. are richly fossiliferous with abundant brachiopods, trilobites, gastropods, and ostracods.

Bloomsburg formation: The Bloomsburg formation of Maryland is the thinned out section of a great wedge of bright red sandstones, siltstones, and shales that thicken to the north-east across Pennsylvania to a maximum of 2300 ft. at the Delaware Water Gap. The red color is due to the presence of the mineral hematite, an iron oxide, which serves to cement the grains. The Bloomsburg represents an alluvial plain environment building westward from a small pulse of mountain building to the east. No fossils have been found in the sandstone members in Maryland.

Wills Creek Formation: Overlying the Bloomsburg fm. in Maryland is a series of calcareous shales, calcareous mudstones and argillaceous (clayey) limestones with several sandstone beds. Mud cracks, ripple marks, and salt crystal imprints occur on many layers. The Wills Creek is the marine facies of the Bloomsburg.

The argillaceous limestones in the upper part of the formation were used as a natural cement rock before the invention of the Portland cement process. The ruins of a cement factory remain on the banks of the C&O Canal at Roundtop, about 3 miles west of Hancock, and several tunnels from which the rocks were mined may be seen along the Western Maryland Railroad.

Tonoloway limestone: The Tonoloway fm. named from Tonoloway Ridge, west of Hancock, consists of an upper and lower sequence of limestones and calcareous shales separated by a thin sandstone member. The limestones of the upper member are sufficiently pure to be quarried and burned for lime. The dessication cracks, algal laminates. and dolomite point to an intertidal environment of deposition. The Tonoloway represents the calms period between the Taconic and Acadian orogenies.

Exercise for Round Top Railroad Cut

Divide into teams of four. Each group will be assigned a 10 ft. long section to describe.

1. How thick are the layers?

2. Color?

3. Grain size? (Clay, silt, sand, pebble)

4. Acid reaction?

5. Rock type?

6. Minerals?

7. Fossils?

8. Mud cracks, ripples, cross beds, laminar bedding, graded bedding?

9. Veins? Composition, orientation relative to bedding?

10. Any anticlines, synclines, faults? Sketch and label.

11. For a 10 foot linear section choose any prominent bed. Measure along the bed following the folds and the faults so that you have the total length of the bed prior to deformation.

    Calculate % shortening = (measured length/10) x 100.

12. Walk along tracks until you see the cave on the north side. Explain.

2

The Silurian section at Roundtop Hill near Hancock, Maryland

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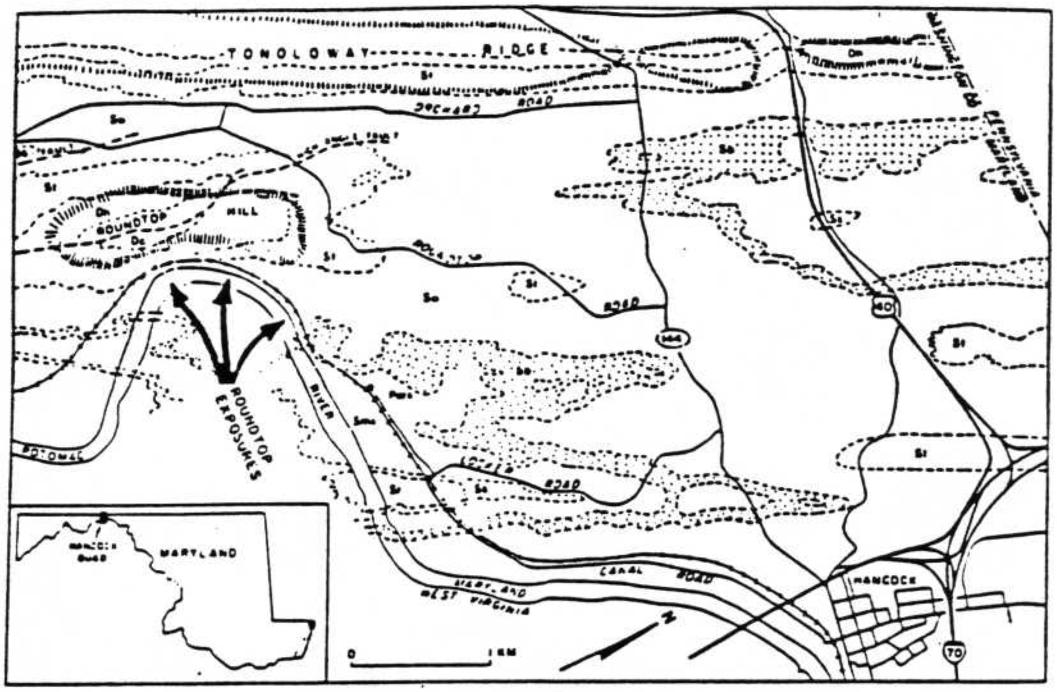


Figure 1. Index map showing location of Roundtop exposures. Sr = Rochester Shale; Sk = Keefer Sandstone; Smk = McKenzie Formation; Sb = Bloomsburg Formation; Sw = Wills Creek Formation; St = Tonoloway Limestone; Dh = Helderberg Limestone; Do = Oriskany Formation.

LOCATION

The Western Maryland Railway cut at Roundtop Hill lies in the Valley and Ridge Province of Maryland, midway between Cumberland and Hagerstown, in Washington County (Fig. 1). The cut can be conveniently reached from I-70 if approaching from the east or north, or from U.S. 40 if approaching from the west. In either case, one must take the Hancock exit and drive south into the town of Hancock, a distance of less than 1 mi (1.6 km). Once in town, two choices of a route to the outcrop are presented. One can elect Canal Road, reached from the center of town by turning south at the traffic light and crossing the railroad tracks (Fig. 1), or one can choose Maryland 144 west to Locker Road and turn south. Either route brings one to a short, unimproved lane that runs west along the railroad tracks for about 0.4 mi (0.7 km) to a small parking area maintained for hunters by the Maryland Department of Natural Resources. The outcrop begins about 0.2 mi (0.4 km) farther west along the tracks.

At the present time, the tracks of the Western Maryland Railway in the vicinity of Hancock are not in use, and there are plans for their eventual removal. Therefore, no permission is required. However, in the unlikely event that these plans are changed and the tracks become active, permission to view the cuts should be sought from the Chessie System offices in Baltimore.

SIGNIFICANCE

The Silurian outcrops at Roundtop, comprising the Bloomsburg and Wills Creek formations, provide the best section of folded rocks in Maryland and are certainly among the finest in the entire Appalachian region. Cloos (1951, 1958) spoke in glowing terms of the Roundtop exposures as a veritable laboratory of the mechanics of folding, formation of cleavage, thrusting, and the deformation of bedded rocks. Specifically, Geiser (1974) pointed to Roundtop as an excellent illustration of the role of pressure solution in the generation of cleavage. Much of the value of the section lies in the fact that deformation at this locality has progressed only far enough to show early structures, but not to the point of obliterating sedimentary features. The importance, then, of the Roundtop section is its prominence as an example of typical Valley and Ridge structural style, and the general excellence of the minor structures displayed.

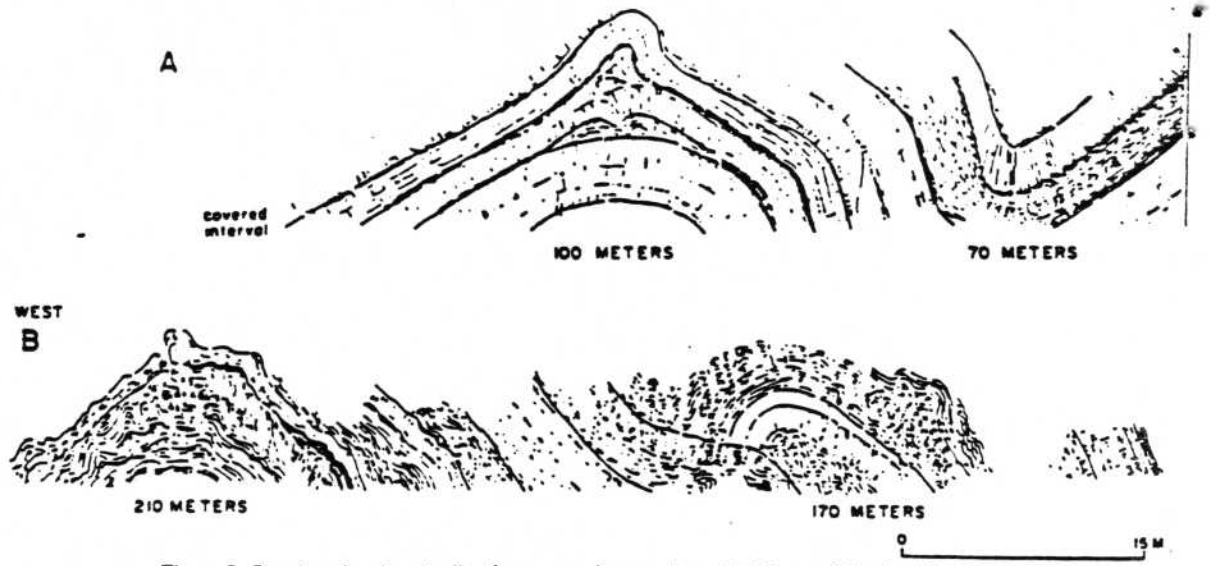


Figure 2. Sketches showing details of exposures in cuts along the Western Maryland Railway at Roundtop Hill. A, easternmost cut, this and facing page; B, western cut.

SITE INFORMATION

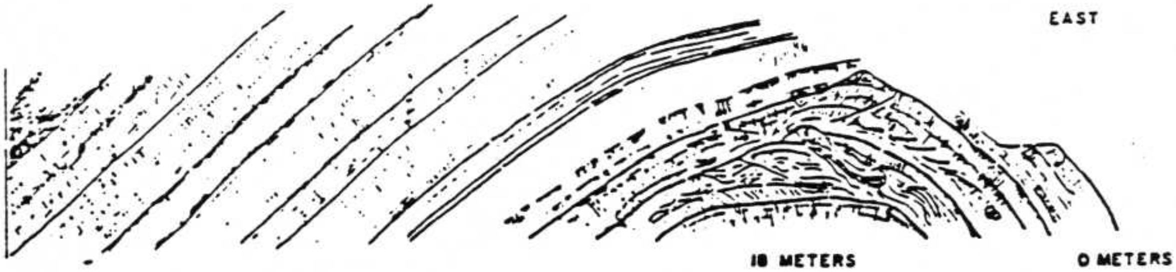
The Valley and Ridge Province of the central Appalachians displays a characteristic structural signature, marked by closely spaced parallel folds and faults with remarkable uniformity along strike. The Cacapon Mountain anticlinorium is one such fold, and it is within the eastern limb of this fold that the Roundtop section is located. Deformation here has been guided by local conditions such as the relative competence of beds, the frequency of failure through low-angle thrusting, and lithologic control of cleavage. This deformation plan is in sharp contrast both with that of the South Mountain anticlinorium, 37 mi (60 km) eastward where a regional penetrative deformation has been imposed over a broad area, and with that of the gently deformed to nearly flat-lying beds typical of the Appalachian Plateau to the west.

The Silurian rocks in the Cacapon Mountain anticline are exposed in a belt about 2.5 mi (4 km) wide between Cove and Tonoloway Ridges, and comprise nearly 1,900 ft (600 m) of strata of which only about 500 ft (160 m) can be seen in the Roundtop cuts. The Wills Creek Formation is exposed in its entirety and dominates the section, but the underlying Bloomsburg, although much thinner, is structurally significant and displays many tectonic features not seen in the other rocks.

The Cacapon Mountain structure, a surface reflection of an underlying ramp anticline involving the Cambro-Ordovician carbonates, is an asymmetric box fold with a gentle northward plunge. Bedding in the west limb rotates from nearly horizontal to steeply dipping over a relatively short distance. The crest of the anticline has collapsed into a large faulted syncline at Roundtop Hill, and the outcrops here display some of the most complex structure in the entire Cacapon Mountain fold. There are at l ten well-exposed third-order folds visible in outcrop along hill. For the most part, the folds are open, and competent b typically have flexure folds showing constant bed thickness bedding-plane slippage. This type of folding is characteristi sandstones and coarse siltstones in the Bloomsburg redbeds contrast, the weaker shales and thin-bedded limestones of Wills Creek Formation are abundantly sheared and thicke into the fold crests and display intense subparallel flow clea

Cleavage, as a persistent plane of parting, is present in ne all of the rocks of the Roundtop section, but it is most consp ous in the shales and siltstones of the Bloomsburg and lower V Creek formations. In these rocks, one can see an array of prc nent subparallel irregular surfaces with a spacing of 1 to 2 generally normal to bedding, and fanning through a large a around the axes of folds. Geiser (1970, 1974) views this struc historically identified as "fracture cleavage," as the produc pressure solution and not the result of brittle failure. He exam minor structures in considerable detail in both the Blooms and Wills Creek rocks and found two generations of clea The first (S_a) is uncommon, has a constant orientation with plane of bedding (always an acute angle), and is selectively veloped in shales bracketed by more competent beds in bot Bloomsburg and Wills Creek formations. S_a is a regional st ture imposed prior to flexural slip folding. The second formed by pressure solution subsequent to lithification as a p uct of bedding-parallel compression, is more widespread predates finite amplitude folding and is locally penetrative.

The Roundtop area is crossed by several large-scale n south oriented high-angle faults (Fig. 1), but none of these



exposed in the railway cuts. Small-scale curviplanar thrust faults are quite common and conspicuous in outcrop. Bedding planes were usually the surfaces along which movement occurred, but in many instances, the thrust surfaces cut through beds at very low angles. Cloos (1964) coined the term "wedges" to describe the wedge-shaped blocks bounded by bedding planes and the low-angle curviplanar thrust surfaces so common in the Roundtop section. The wedges occur at all scales, in beds 6 to 10 ft (2 to 3 m) thick as well as those only a few cm thick. The host rocks are nearly always massive siltstones or coarse shales in the Bloomsburg Formation, but some wedges occur in the Tonoloway limestones. Careful measurements and stereo net plots by Geiser (1974) showed that the wedges in most cases have a westward sense of transport and occur on both the limbs and crests of folds. This evidence tends to support the earlier conclusion of Cloos that wedging took place in response to regional bedding-parallel compression prior to folding. Geiser (1974) also hypothesized that the wedging postdated the formation of S_p cleavage since cleavage is rotated by motion on the wedges. The majority of "wedge slips" examined resulted in thickening of the faulted beds, but exceptionally, thinning can be observed. Thinned beds were termed "lags" by Geiser and were ascribed to local movements concurrent with folding. Cloos visualized the overall process as a crowding of material outward from the limbs of the folds with a multitude of small thrusts serving as movement planes.

Approaching the exposure from the east, the first cut reveals a complexly faulted anticline (Fig 2A, at 18 m) in Bloomsburg red shale and sandstone. Of major interest here is the behavior of the thin sandstone bed in the lower portion of the section that has been telescoped and repeated by thrusting as much as six times. The associated shales show excellent fanning cleavage. Some of these shale beds, particularly the laminated and crenulated greenish bed above the sandstone, have clearly served as planes of slippage. It is also worth noting that the degree of deformation in this outcrop is too severe to be related only to the anticline in this cut, and moreover, the telescoping of beds is asymmetric with respect to the axial plane of the fold. Rather, such movements may be accommodations within the much larger Cacapon Mountain fold, or even be due to bedding plane slippage caused by gravity sliding or slumping prior to lithification and folding.

Proceeding westward, one passes steadily upward through evenly dipping beds of soft, poorly-consolidated mudstone and shale of the Wills Creek Formation, and about 164 ft (50 m) beyond the first anticline encounters a tight syncline with conspicuous axial-plane cleavage, some rotated blocks on antithetic faults, and low-angle thrust faults in the west limb (Fig. 2A, at 70 m). About 100 ft (30 m) farther west and downsection is a second anticline (300 ft; 100 m) which shows a textbook example of the contrast in response between competent and incompetent beds during tight folding. The less competent shales have flowed into the fold crest, whereas the more competent red siltstone has thickened into the crest by repeated low-angle thrust faults. The sliding of competent beds past one another along bedding planes to accommodate the growing fold produced well-defined bedding plane striations. Beyond the second anticline, and covered at track level, are about 160 ft (50 m) of west-dipping calcareous siltstone, mudstone, and limestone of the Wills Creek Formation. These rocks show cleavage normal to bedding, and, in part, at a low angle to bedding as a result of rotation due to bedding plane slippage. Visible at about this point, several meters above track level, is a partially collapsed tunnel excavated in thin-bedded argillaceous limestone that has the approximate composition of cement. Other tunnels were diven here at canal level, and the site is marked by a ruined cement kiln in operation at the turn of the century. Just west of the tunnel is a tight syncline followed by a short covered interval.

About 50 ft (15 m) farther along, the section resumes with an asymmetric, faulted anticline that has been thrust westward at a low angle over the broken west limb of the fold (Fig. 2B at 170 m). The thrust plane is clearly shown in the outcrop, as is small-scale crumpling of the thin-bedded limestones involved in the anticline. As noted before, the siltstones in the section are the least deformed lithology but show the strongest cleavage. Walking west along the tracks for another 130 ft (40 m) and downsection through east-dipping Wills Creek strata, we encounter another anticline (Fig. 2B, at 210 m) involving thin-bedded limestones and calcareous siltstones. This fold is essentially symmetrical but the limbs are crowded with minor folds, developed partly in response to flexural slip. Some earlier workers termed these folds "drag folds," but Geiser (1974) believes that some of them are really a type of conjugate kink fold formed during the final stages of deformation. These kink folds are most apparent in limbs that show reversal of movement sense in consecutive beds.

A second tunnel can be seen high on the slope from a point 100 ft (30 m) farther west along the tracks, beyond the exposures shown in Figure 2B. The rocks here have a steep westward dip. Over the succeeding 200 ft (60 m), the dip remains westward but becomes less steep and passes into a very tight syncline in which beds were conspicuously crowded toward the fold axis with attendant crumpling and small-scale thrusting.

Another 60 ft (20 m) brings one to a paired anticline and syncline, both with steep limbs marked by thin crumpled limestone beds and thrust displacement toward the axes of the folds. The thick calcareous shale at track level displays excellent fan cleavage. A few paces farther west, about midway in the railway cut, is an excellent example of desiccation cracks in a light greenish gray shaly limestone. Just beyond the desiccation cracks is the entrance to the third and largest cement mine, in this case excavated into the core of a large tight anticline. The tunnel is steeply inclined and opens into a large chamber.

The next 300 ft (90 m) of the exposure consist of uniformly dipping mudstone, shale, and thin-bedded limestone and sandstone. In places, the limestone beds are selectively folded. At the 300-ft (90-m) point is a small anticline marked by small-scale folding and telescoping in the thin rusty sandstone beds that make up the core of the fold. About 25 ft (8 m) beyond the anticline is a thick bed of green silty shale with conspicuous cleavage at acute angle to bedding. This is a good example of Geiser' cleavage. Thirty ft (10 m) farther along, S_a cleavage is very developed in shaly beds involved in a fairly open syncline.

The dip reversal on the west limb of the syncline repeat foregoing section for the next 700 ft (60 m) of traverse. The dip eastward, steeply at first, then more gently as the next cline is approached. Between these two folds, further exampl S_a cleavage at an angle to bedding can be seen in a thick ste dipping green shale bed a few feet beyond the syncline. A site, the S_a cleavage has been folded. A few paces farther alc sequence of thin fine-grained sandstone beds shows conside minor folding with many beds broken and thickened by we Similar structures are present in places over the next 1 (40 m) of otherwise homoclinal section until a large open cline, with prominent fan cleavage in the thick shaly be encountered.

The section can be followed for about another 1,· (440 m) before the exposure ends, but the beds dip unif west, and no further structures of interest are to be seen. All rocks in this homoclinal sequence are within the Wills Formation. Limestone visibly increases in abundance as th tact with the overlying Tonoloway Formation is approach

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Identification of Common Fossil Organisms for Introductory Geology

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ABSTRACT

Fossil organisms and relative-age studies are inseparably related to geologic time. They provide both a foundation for those students who take historical geology, and an appreciation for fossil organisms and their preservation. However, some instructors may feel insecure about their ability to teach fossil recognition. Identification keys are the basic tools used for identifying organisms in the biological sciences. This format can be adopted for the identification of fossils when introducing geologic time in the introductory geology laboratory. The "key" format presented here organizes common fossils into three major groups based on symmetry: radial, bilateral, or no apparent symmetry. Some fossils may be found in more than one category. Observation of various characteristics beyond symmetry enables the student to identify fossils to phylum and, in some cases, class. This method reinforces student learning and provides an orderly approach for introducing common fossils. The problems and expense of acquiring a fossil collection for the introductory laboratory can be overcome by: (1) sharing specimens; (2) applying protective coatings; (3) using plastic or plaster casts; and (4) trading mineral, rock, and fossil materials among institutions.

Key words: Earth science teaching - laboratory; introductory course; geology teaching; paleontology - general.

INTRODUCTION

When geologic time is introduced in physical geology, the concepts of relative and absolute dating, fossils, and stratigraphic principles are usually briefly discussed. These concepts are important for the introductory student, for without this background, students cannot fully understand sedimentary rocks, geologic structures, and plate tectonics. It is important that geology students begin to think beyond the limited time (hours, weeks, years) of their daily lives and in terms of millions of years. This is necessary for an appreciation of the time requirements for geologic and geomorphic processes. A good understanding of geologic time also provides a better foundation for those students who may go on in geology.

Fossil organisms and relative-age studies are inseparably related to geologic time. Students seem to show a natural interest in prehistoric life, and many students were fascinated by fossil organisms, such as dinosaurs, in elementary school. Fossil displays in museums are very popular and after viewing them informed students consider the significance and preservation of ancient life with increased understanding. This interest can be exploited in the college level introductory geology course because most students still find these subjects very stimulating.

We feel it is important to introduce geologic time and fossil materials in both lecture and laboratory. This provides a foundation for those students who take historical geology, and an appreciation for fossil organisms and their preservation for those students whose only exposure is an introductory course. Unfortunately, only a few physical geology laboratory manuals introduce geologic time and stratigraphic principles, or discuss fossils (Davis, Eves, and Rohde, 1986, O'Dunn and Sill, 1986).

Even if fossil identification is part of an introductory geology curriculum, instructors who do not have a background in biology or paleontology often feel insecure about presenting fossils in the laboratory. Although many had introductory paleontology as part of their undergraduate geological education, they may have forgotten important concepts, names, and classifications after years of non-use. Those instructors who do cover fossil organisms often utilize pictures rather than specimens and end up with their students doing mere "stamp collecting" rather than developing a genuine understanding of systematic fossil organism classification. We propose the following as a simple and straightforward approach to teaching and understanding fossils in the introductory physical geology laboratory. This system requires that students make observations and reach conclusions based on body morphology.

FOSSILS: A METHOD OF PRESENTATION

An introduction to the different types of fossils: for example, casts, impressions, and fossilized hard parts; and modes of fossilization (recrystallization, replacement, and carbonization) should be presented. A brief explanation of index or guide fossils and their utilization for correlation, relative dating, and environmental interpretation can also be included. Most of this material is straightforward and easily grasped. It is the identification and classification of fossils that seem to cause the most problems.

The following fossil identification system (Table 1) for common organisms in the introductory laboratory is easy to use. It is based on the "key" system that has long been used in biological identification, and in recent years successfully adapted for the identification of igneous, sedimentary, and metamorphic rocks in physical geology (Davis and Eves, 1986; Eves and Davis, 1987). Biological symmetry provides the foundation for utilization of this system in fossil identification. A laboratory explanation of symmetry is necessary, but even ardent nonpaleontologists can soon recall this concept and teach it to introductory students.

Symmetry

Symmetry is defined as the arrangement of body form about a central axis or plane. For the purpose of this key, the hierarchy for symmetry (in decreasing order) is radial, bilateral, or no symmetry. All forms which exhibit radial symmetry also possess bilateral symmetry, but organisms are always classified according to the highest symmetry present. Some forms, for example echinoderms, which show bilateral symmetry also show imperfect radial symmetry. For the sake of clarity and to simplify the use of the identification key, some organisms have been placed into more than one symmetry classification.

Radial symmetry is the condition of having similar parts regularly arranged about a central axis (like spokes on a wheel), for example, certain corals and cephalopods (Figure 1 A and B).

Bilateral symmetry is the condition of having equal right and left sides, such as trilobites and brachiopods (Figure 1C) or equal top and bottoms, such as bivalves (Figure 1D).

Nearly all organisms show some type of symmetry; however, in some organisms such as colonial organisms (corals and bryozoans – Figure 1 E and F) symmetry may be difficult

Identification of Common Fossil Organisms

I. Observe symmetry in fossils

A. Displays radial or imperfect-radial symmetry	II
B. Displays bilateral symmetry in at least one plane	III
C. Displays no apparent symmetry	IV

II. Radial or Imperfect Radial Symmetry

A. Tapering; cylindrical; cigar- or cone-shaped.

1. Smooth, cigar-shaped; radiating calcite needles in cross-section.
   MOLLUSCA (Cephalopods)

2. Poorly developed radial symmetry; tapering; irregular horn- or cone-shape; several may grow together as a colony.
   CNIDARIA (Corals)

3. Small (1-5mm); football-shaped.
   PROTISTA (Forams)

B. Composed of segments or plates; may or may not taper.

1. Tapering; stacked circular segments.
   MOLLUSCA (Cephalopods)

2. Non-tapering; stacked discs or plates; discs may have small protrusions; may have hole in center of discs.
   ECHINODERMATA (Crinoid Stems)

3. Composed of interlocking segments or plates.

   a. Rosebud-shaped
   ECHINODERM (Blastoids)

   b. Cup- or flower-shaped; cup may have many branching appendages (arms); may be attached to crinoid stem.
   ECHINODERMATA (Crinoids)

III. Bilateral Symmetry in at least one plane

A. Coiled forms, snail-like.

1. Coiled in plane of bilateral symmetry; may show internal walls or partitions.
   MOLLUSCA (Cephalopods)

2. Perfect to irregular coil perpendicular to plane of symmetry; may show internal walls or partitions; snail-like.
   MOLLUSCA (Gastropods)

B. Non-coiled forms.

1. Shell halves equal or nearly equal in shape and size.

   a. Plane of symmetry parallel to shell half.
   MOLLUSCA (Bivalves)

   b. Plane of symmetry perpendicular to shell, as well as parallel to shell half.
   MOLLUSCA (Bivalves)

2. Shell halves unequal in size and shape; larger shell half often shows a prominent beak with strong ridge; smaller half often has a prominent depression.
   BRACHIOPODA (Brachs)

3. Tapering, cone-, tusk-, or horn-shaped.

   a. Cone- or horn-shaped (may be irregular); transverse walls or partitions (like spokes on a wheel).
   CNIDARIA (Corals)

   b. Tusk-shaped; smooth or ribbed external surface; opening at both ends; no internal walls or partitions.
   MOLLUSCA (Scaphapods)

4. Circular- to heart-shaped; flattened disc or domed; star pattern on upper surface; like a sand dollar.
   ECHINODERMATA (Echinoids)

5. Body segmented into distinct head, thorax (body), and tail regions.

   a. Bug-like; divided into three body lobes; may have appendages; often only semi-circular head and tail regions are preserved.
   ARTHROPODA (Trilobites)

   b. Appendages often very distinct; resembles crab, shrimp, or crayfish.
   ARTHROPODA (Crustaceans)

6. Leaf- or fern-like; commonly found on bedding surfaces of mud/siltstones.
   LEAF FOSSIL

IV. No apparent symmetry

A. May show coiling, but without internal transverse walls or partitions.

1. Coiled like a horn; low spired; opening of shell very large; ribbed surface (may be concentric); two mirror-image shells may be present.
   MOLLUSCA (Bivalves)

2. Tightly coiled; most are high spired; looks like a snail.
   MOLLUSCA (Gastropods)

3. Solid spiral ridge around a central axis; resembles a corkscrew.
   BRYOZOA (Ramose Bryozoa)

B. Not coiled.

1. Resembles a narrow saw blade; straight or curved; may be joined like branching leaves; commonly appears as carbon film on flat surfaces of shales and slates.
   HEMICHORDATA (Graptolites)

2. Irregular cone-shaped; longitudinal and radial walls or partitions.
   CNIDARIA (Corals)

Table 1. Identification of fossils to phylum based on symmetry. (Continued on next page.)

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3. Resembles a clam or oyster shell; shell not symmetrical. MOLLUSCA (Bivalves)
4. Cup-shaped; branching arms; flower-like; may have attached stem. ECHINODERMATA (Crinoids)
5. Branching, twig-like.
a. Covered with minute pores or openings. BRYOZOA (Ramose Bryozoa)
b. Evenly distributed 1-4mm openings or pores; radial partitions in openings. CNIDARIA (Corals)
6. Lace-like; usually thin sheets. BRYOZOA (Fenestrae Bryozoa)
7. Composed of radiating mass of polygonal or circular tubes containing radial walls or partitions. CNIDARIA (Colonial Corals)
8. Resembles woody material; commonly replaced by quartz; wide variety of colors. PETRIFIED WOOD

Table 1. Identification of fossils to phylum based on symmetry. (See previous page.)

to observe. Such organisms are, therefore, included in the "no apparent symmetry" catagory.

Other Distinguishing Characteristics

Once the symmetry has been determined, other recognizible characteristics such as size, shape, coiling, and partitioning are used to classify fossil organisms to the common phyla; in most cases, fossil organisms can be identified to class. Our teaching experience has shown that some terms, for example, conical; cone-, horn-, and tusk-shaped; low and high spiral; coiling; and partitioning, may have to be defined and illustrated with simple diagrams.

The major hurdle in fossil identification at this level is to get introductory students to use their imaginations and creativity, and overcome the tendency toward looking for absolutes. For instance, blastoids are described as rosebud-shaped, but students commonly complain, "that doesn't look like a rose!". Therefore, it is important for the instructor to be patient and explain that it is the general or gross characteristics that are similar.

One of the goals of introducing fossil organims in physical geology is to teach students to draw conclusions based on observations. Having students learn to use the key is more important than having them learn to "sight" identify several phyla of fossils. In our experience, it is best to allow students to utilize the key during examinations.

Fossil Materials

Another problem often encountered with regard to teaching a laboratory on fossil identification is the availability of material. People in a few regions of the country have easy access to abundant and diverse faunas, but most have limited resources. Fossils are expensive to purchase and, because they are fragile, there is need for continual replacement.

We have solved these problems in several ways. The first time we included a fossil lab in our physical geology course, each student was provided an individual set of specimens. However, it was found that for classes of 20 or less, students could share a single tray of fossils so that only one or two specimens of a particular genus were needed. We then increased the number of variations, for example, two or three different genera of brachiopods and trilobites. This also demonstrates that there is wide variation within taxonomic groups of fossils organisms.

For some fossils, such as ammonoids, it is also useful to have one specimen cut in half along the plane of symmetry to aid students in recognizing such parameters as partitioning and coiling. Coating the specimen with plastic or other sealants will increase its durability.

Good examples of many fossils are difficult, as well as expensive, to obtain, particularily in large numbers. Plaster or plastic casts of these fossils are just as serviceable, and because they are inexpensive they can be produced in large numbers (saving the original for future needs). (See Converse, 1984, for casting techniques).

Another approach to obtaining laboratory specimens is to contact departmental geology clubs or Sigma Gamma Epsilon chapters in areas known to have abundant fossil materials. In this way, specimens can be acquired at less expense than through a commercial outlet. Better yet, perhaps a trade of material might be worked out (We at WSU are willing to trade basalt by the ton, for just about any fossil material by the pound!)

SUMMARY

When discussing geologic time in introductory geology, we feel it is important to introduce fossils in both the lecture and the laboratory. The fossil identification key enables the student to easily identify common fossils to phylum and, in many cases, class. Even those instructors who have not looked at fossil organisms in a decade will find the proposed system "user-friendly" once they demonstrate the principles of bilateral and radial symmetry. Fossils can be a fascinating topic in introductory geology, and can aid in stimulating further interest in the geological sciences. We feel our method of introducing fossils will be a more rewarding experience for both the student and the instructor.

ACKNOWLEDGEMENTS

The authors thank Dr. Monte Wilson, Department of Geology and Geophysics, Boise State University, Boise, Idaho, and Dr. Thaddius Dyman, U.S. Geological Survey, Denver, Colorado, for their detailed comments and suggestions during the preparation of this manuscript. Financial support for this project was provided by the Department of Geology, Washington State University. Figures A-F were reproduced, with permission, from Moore, Lalicker, and Fisher (1952).

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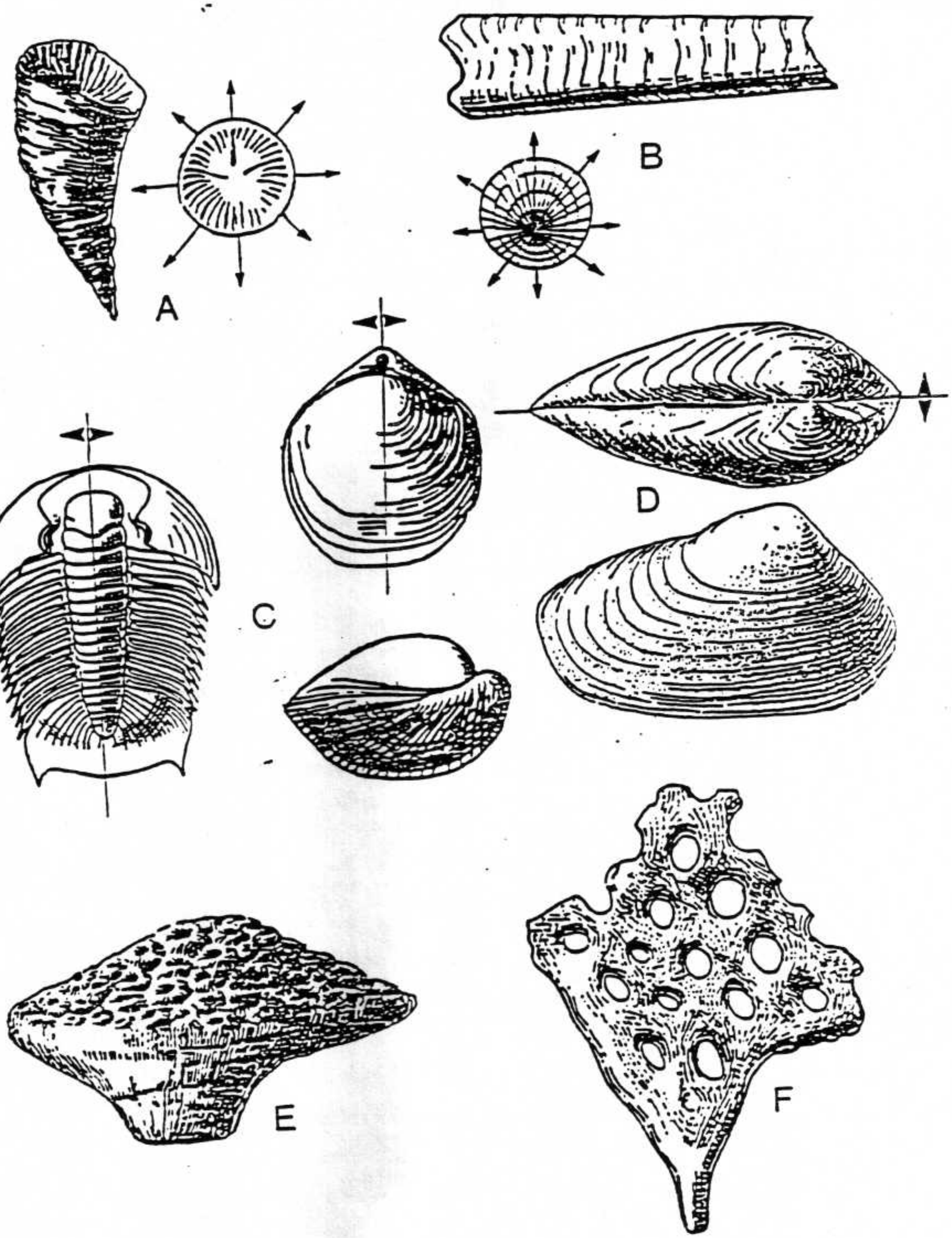

Figure 1. Symmetry in fossils.

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Summary Stratigraphy of the Central and Northern Shenandoah Valley

Sequence	System	Formation	Thickness	Description	Deposits	Orogeny
KASKASKIA	MISS	Mauch Chunk	not present northern Virginia	S.S. coarse, channels. SILT/SH gray/blk, plant foss abndt in places. COAL	Molasse	
		Greenbriar		L.S. (micrite, calcar, oolite) some qtzitic, gray (red in places), Foss common		
		Pocono	300-1700	S.S. qtz, gray/white, coarse, thick bed, x-bed, little SH. CONGL (qtz) in places.		Acadian Orogeny
	DEVONIAN	Hampshire (Catskill)	2000	S.S. red, thick bed, arkosic, mica, x-bed, plant frag. MUDST red, thick bed.		
		Chemung	2000	S.S. med/thick, med gr, gray/grn. SH grn, soft CONGL (qtz) & S.S./SH (red) scat thru-out		
		Braillier (Portage)	1500-1700	S.S. (fine, black)/ SH thin/med, olive, weath tan, cur marks/trace com, foss rare.		
		Millboro (Used south of Shenandoah Co.) — Mahantango	900	MAH: SH dk-gray/blk, fiss, weath silver-gray, dwarf foss, pyrite. MAH: Bot-Mid: SH/SILT, grn, thin. Top: S.S., fine, mass/thk, fos may be abn		
		Marcellus	350-550			
		Tioga Bentonite	80-100	SH/SILTS gray interbedded with TUFF calc.		
		Onondaga (Needmore)	100-530	SH silty, olive, weath nonfiss, chalky, yellowish, bot very foss, grades into Marcellus		
		Regional Unconformity — In SW Va. Onondaga lies on Martinsburg.				
TIPPECANOE		Oriskany (Ridgley)	10-125	S.S. qtz, coarse to congl, calc (friable) or SiO_2 cement, white/gray/tan, foss mod/abndt		
		Helderburg Group — New Scotland	70-150	KEYS: L.S. gray, weath brn bot-wht top, fine/med, foss abndt. NEWCRK: L.S. gray, coarse, crinoidal. NEWSCOT: L.S. dk-gray, med grain, abndt foss. CHERT white/black, massive.		
		Helderburg Group — New Creek (Coeymans)	17-50			
		Helderburg Group — Keyser	70-600			
		Tonoloway	50-250	L.S. argill, gray/yellow, fine lam, mud crks, F.P. congl, ostra abndt. Interbed with Keyser		
	SILURIAN (CAYUGA)	Wills Creek	60-150	BLOOMS: S.S./SILT/SH red/grn, s.s. w/ Fe_2O_3 cem. WILLS CRK: SH, sandy/silt, calc, yellow/brn w/ L.S. gray/red, foss (ostra, bryo, brach)		
		Bloomsburg	0-400			
		McKenzie	0-75	SH calc, yellow, fossils (esp ostracods)		
	SILURIAN (CLINTON)	Keefer — Massanutten	70 (Massanutten 700-1200)	MASS: S.S. qtz, white, locally CONGL & thin blk SH, trough cross-bed abndt. TUSC: Bot qtz CONGL; Top QTZITE white, thick. ROSE HILL: SH sandy, yel-brn; S.S. fine/med, gray/brn, red S.S. at top, abndt foss in places. KEEF: QTZITE gray/white, cross bed, base grn/purp SH		Taconic Orogeny
		Rose Hill — Massanutten	650			
		Tuscarora (Clinch)	50-250			
	ORDOVICIAN	Juniata (Local Unconformity in Massanutten Mtn)	0-200	S.S./SH red, choc, white; S.S. fine/med, thin/thick; Cross bed in thick S.S.		
		Oswego	0-375	S.S. med/thick, coar, green/gray, brown weath CONGL in places. Scat thin red S.S. beds		
		Martinsburg	3000	Bot: L.S. blk + METABENT. Mid S.S./SH alter gray/green, rust weath. Top: S.S. Source foss	Flysch	
		Oranda	40-60	Very var: SILTST gray, calc; SH blk; MUDSTO calc; L.S. gray, nodul. Lst foss. METABENT.		
		Local Unconformity				
		Edinburg	425-600	Var, gen L.S. nodular weath, thin/med, dk-gray/blk; SH blk, thin; Foss abundant.		
		Lincolnshire	25-170	L.S. dk gray, med/coarse, med/thick; CHERT blk, bed; Foss beds common, lt gray. Top nodular.	Continental Margin Deposits	
		New Market	40-250	Bot: Basal carb/chert congl, thin bed L.S. abov Top: L.S. fine, blue, weath white, thick bed.		
		Regional Unconformity				
SAUK		Beekmantown (Rockdale Run)	2000-2500	DOLO thk bed, fine gr, lt-dk gray, L.S. blue-gray. CHERT black, white. Foss com. Many stru		
		Chepultepec (Stonehenge)	500	L.S. thick bed, blue, fine, crinkly weath. DOLO rare. F.P. Congl. Oolites. Rare foss but widesp		
	CAMBRIAN	Conococheague	2500	L.S. blue-gray, lam; DOLO lt gray, mass, fine. S.S. qtz. Scenms., F.P. Congl. Few foss.		
		Elbrook	2000	L.S. blue-gray, yellow weath; DOLO laminated. Algal L.S. in top 300'.		
		Rome (Waynesboro)	2000	Very var. SH red/green; S.S.; DOLO granular; L.S. blue-banded. Scantily fossiliferous.		
		Shady	1600	DOLO granular; L.S. beds at top & bottom. Few foss except a few scattered l.s. beds.		
		Erwin-Antietam (CHILHOWEE)	500-1500	S.S. qtz, fine/medium, thick/massive, gray, weathers white. Scolithus burrows.		
		Hampton (Harpers) (CHILHOWEE)	2000	SH Thin-bedded, fine-grained and S.S. dirty. Rusty weathering. Metamorphosed.		
		Weverton (CHILHOWEE)	600	S.S. qtz, coarse, massive and CONGL qtz, alternating with phyllitic SH. Many layers purplish		
		Regional Unconformity				
	PreC	Catoctin		Greenstone		

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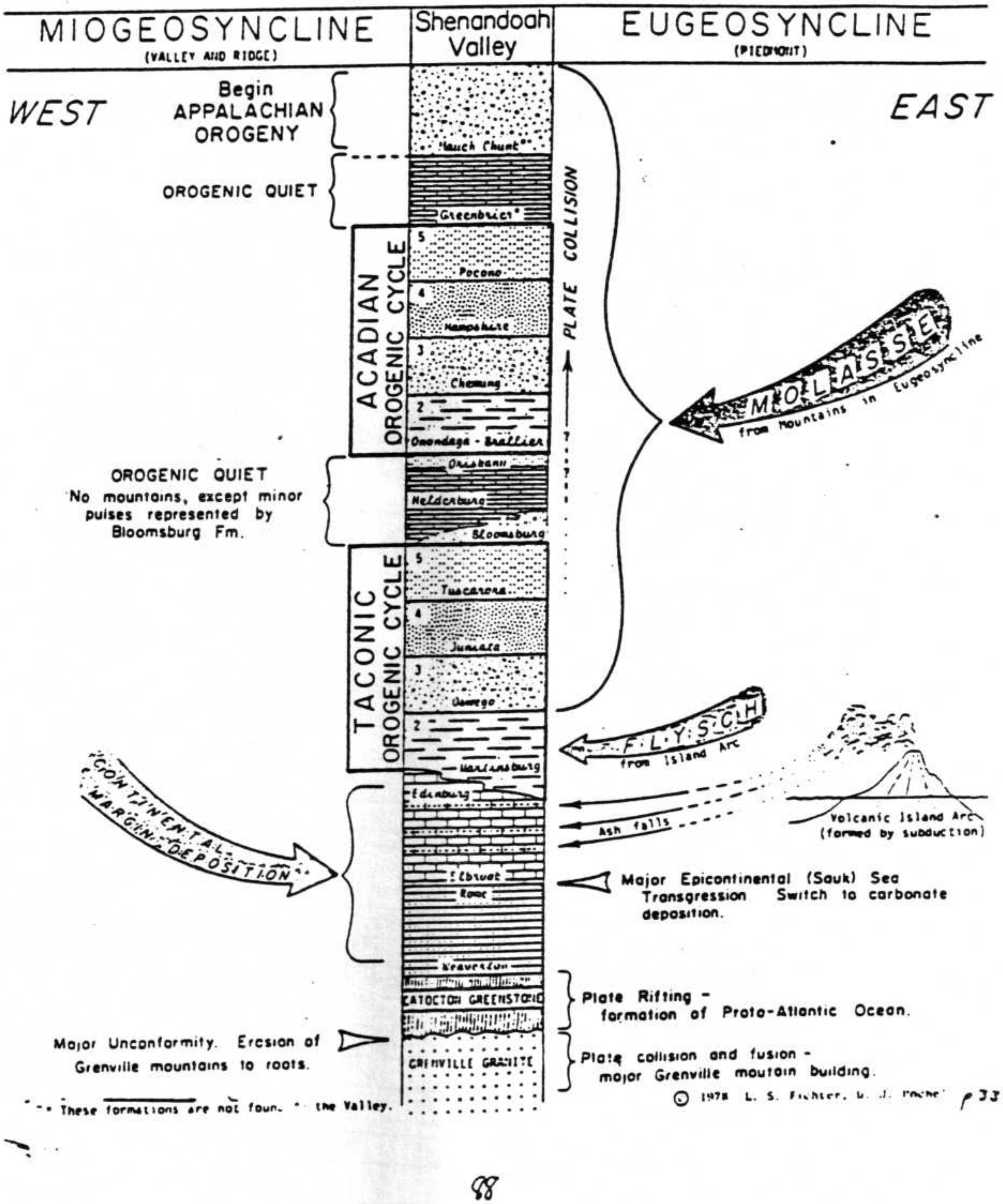
Geologic History of the Shenandoah Valley As Preserved in the Local Section



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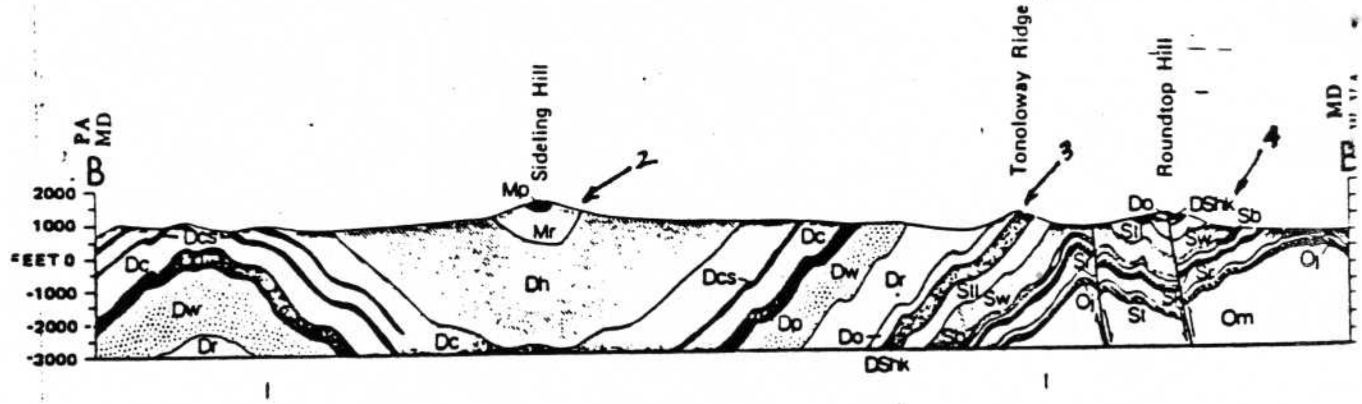
ROAD LOG:

0.0	STOP 1	Fort Frederick (Return to I-70 West)
18	STOP 2	Sideling Hill
		go west on 40 and make U turn at next exit.
		Retrace route eastward to next exit which is Woodmont Rd. or Rt. 144, toward Hancock.
		Left on 144 to first road on left, Sandy Mile road
		Proceed one mile to quarry at bridge over rt. 40.
	STOP 3	Abandonned Carbonate Quarry and Sandstone Cliffs
5		retrace your path to Rt. 144 and turn left to Hancock
		Proceed to Wedemeyer Memorial Park (Lunch)
0.7 app		Head east on Main St. (Rt. 144) to lights at Penn. Ave. Turn right on Penn. Ave.
0.1		Turn right on Canal Road and follow along C & O Canal
2		Cross the R&R and then take immediate left onto dirt road which is LOCKER Rd.
0.6		Proceed to the end of straight road and park.
	STOP 4	Walk the abandoned Western Maryland tracks westward to outcrops (15 minutes app.) return by way of the Canal if time permits

GEOLOGIC CROSS SECTIONS

Horizontal scale same as map, no vertical exaggeration.



Symbol	Rock Unit	Age	Description	Environme
Mp				
Mr				
Dh				
Dc				
Dcs				
Dp				
Dw				
Dr				
Do				
DShk				
STL				
Sw				
Sb				

GEOLOGIC MAP OF WASHINGTON COUNTY, MGS, J. EDWARDS, JR., 1978

THE FALLS STRETCH OF THE POTOMAC RIVER -- A GEOMORPHIC "CROSS-SECTION" OF THE FALL LINE ON THE WESTERN EDGE OF THE ATLANTIC COASTAL PLAIN

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INTRODUCTION

Throughout the middle Atlantic slope, the boundary of the Coastal Plain is salient. Commomly known as the "Fall Line," this geomorphic boundary is more properly a Fall Zone - a quasi linear landscape formed by the pre-Cretaceous morvan of the eastern Piedmont Plateau, lapped by the southeastward thickening wedge of stratified Coastal Plain deposits. Across this zone, the course of major rivers and streams abruptly changes in a series of cascades or rapids from narrow rock-bound gorges formed on the highly altered crystallines, to broad estuaries on the unconsolidated clastics. Longitudinal river profiles demonstrate a marked steepening or disequilibrium. Within only a few miles of tidewater: the Susquehanna falls 80 feet, 12 miles from tidewater (now submerged by Conowingo Dam); the Rappahanock drops 100 feet in 12 miles, and the James decends to tidewater falling approximately 80 feet in three miles. Similarly the Potomac falls at least 40 feet in three miles and 130 feet in approximately 14 miles.

Near the nation's Capital, the Falls Stretch of the Potomac River forms a roughly linear (7 km. long by 1 km. wide) transect across the Fall Zone/eastern crystalline Piedmont of Maryland and northern Virginia, from Theodore Roosevelt Island, Washington, D. C. upstream to Seneca, Maryland (Fig. 1). Along this spectacular valley, the Potomac has incised, locally stripping bedrock, revealing exceptional field exposures of Piedmont plutonic and meta-sedimentary sequences, tectonic deformation structures and mineralization features. Marked by Plesistocene eustatic base level effects, and post-glacial flow variations, the Potomac valley also displays an equally impressive geomorphic array of fragmented fluvio-esturine terraces, a complex pattern of soil development on aeolian, fluvial, and colluvial deposits, as well as bedrock straths, bedrock-cored islands, rock-defended and alluvial channels, fan-deltas, falls and rapids. Clearly, the Falls Stretch of the Potomac is an essential field site for both the student and the researcher seeking clarification on the issues of east coast tectonism and Pleistocene eustasy.

THE GEOLOGIC SETTING

Along the Potomac near Washington, D. C., the crystalline bedrock of the Piedmont includes two major units of the Wissahickon terrane and several other units of more limited geomorphic impact. Both Wissahickon terrane units are believed to be late Pre-Cambrian/early Cambrian: (1) the Sykesville Formation, Hopson (1964); and (2) Peters Creek Schist, redefined by Drake and Morgan (1981), or Wissahickon Formation, western sequence Fisher (1963), Hopson (1964). These two units are in allochthonous (thrust sheet or nappe) contact, with the Peters Creek sitting on the Sykesville (A.A. Drake Jr., 1977, Drake and others, 1979). Clasts of deformed mafic and ultra-mafic rocks, within both the Peters

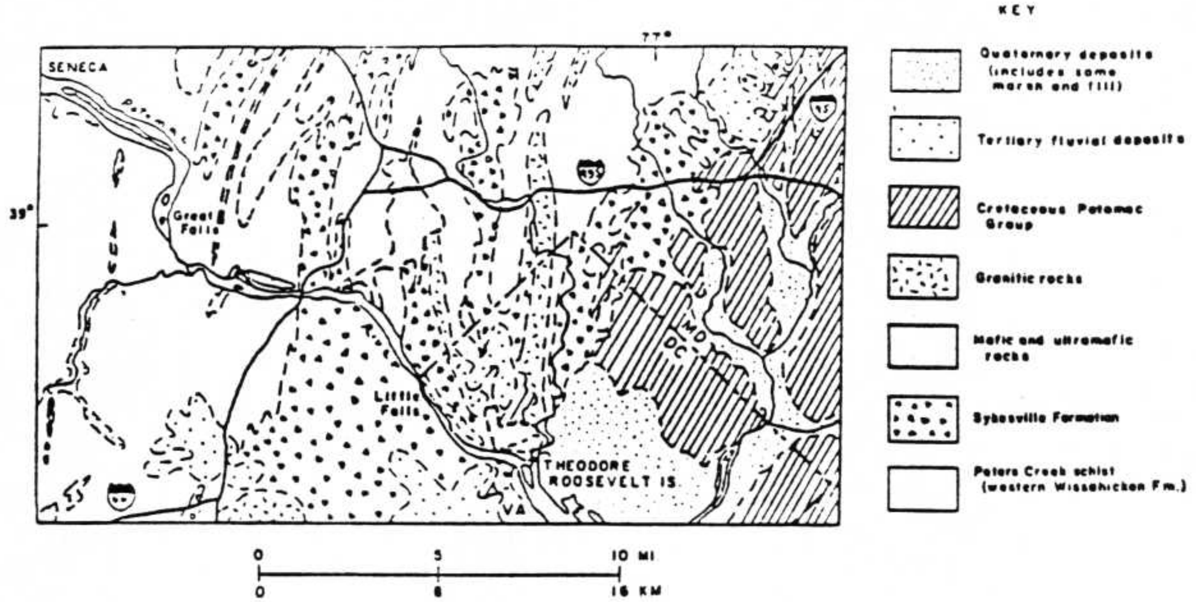


Figure 1. Generalized geologic map of the Fall Zone--Falls Stretch of the Potomac River area near Washington, D.C. Modified from the compilation by Reed and Obermier (1982), Tormey (1988).

Creek and the Sykesville, suggest movement of Central Appalachian ophiolite (Drake and Morgan, 1981), northwestward along the limbs of the antiformal structure or window (Rankin, 1975) formerly called the Baltimore-Washington anticlinorium by Fisher (ms) and by Hopson (1964).

The present-day Piedmont/Coastal Plain boundary is the result of the Ordovician Taconian/Humberian Orogeny, overprinted by later orogenic forces and climaxing in Triassic block faulting and later marginal continental flexure. Prior to Tormey's (1980) study, Pleistocene coastal geomorphology in Maryland did not correlate well with other eustatic base level studies along the Atlantic Coastal Plain. As a river traversing three landform provinces, Ridge and Valley, Piedmont, and Coastal Plain, exposures in the Potomac Falls Stretch are intimately tied to these events.

The Sykesville Formation has been redefined and reinstated (Drake and Morgan, 1981), as a sedimentary melange (mixture of exotic and native blocks and fragments) with a psammitic (sandy) granofels matrix, probably complicated by massive subaqueous sliding. While this unit has considerable textural variability, its most distinctive feature is the numerous inclusions of rounded knots of quartz, flattened mica schist fragments, and angular fragments of metagreywacke (Fig. 2). In addition to inclusions of foreign rock noted by Hopson (1964) and Fisher (1970), Drake and Morgan (1981) have observed chips, blocks and slabs of schist and metagreywacke of the Peters Creek in Sykesville matrix, indicating the contact is tectonic rather than gradational, as previous workers observations appeared to indicate. Locally, the formation shows a wide degree of variability in texture, with some outcrops presenting tiny inclusions

Figure 2. Sykesville formation along Seven Locks Road, near Emory Corners, Maryland.

difficult to distinguish from the surrounding matrix, while others reveal fragments 1-2 microns in size. Mineralogically, the rocks are quite uniform (Hopsoh, 1964), consisting of up to 90% quartz, plagioclase, and muscovite in varying concentrations, with biotite, chlorite, epidote, magnetite, and garnet as prominent dark minerals. See Plate 1 (in pocket).

The <u>Peters Creek Schist</u> (or Wissahickon Formation, western sequence) forms a broad northeast-trending flyschoid belt of mainly metasedimentary argillaceous fine-grained rocks, rhythmically interbedded with more coarse, metagreywacke beds and local tuff beds, that extends across Maryland from the Fairfax, Virginia vicinity into southeastern Pennsylvania. The Potomac River's incised gorge affords an exceptional cross-section exposure of both the prograde and retrograde metamorphic alterations, as well as a variety of preserved primary structures (Fisher, 1970). Near Seneca, the argillaceous rocks are fine-grained, chlorite-sericite schists, frequently containing pods, knots and veinlets of quartz, that weather commonly into prominence creating rough, ribbed, knobby outcrops. Farther east, metamorphic grade peaks near Bear Island (downstream form Great Falls), where the coarse-grained mica schists include large aluminum silicate porphyroblasts. Where locally injected by pegmatitic granite, the rocks are more like migmatized (mobile or partially mobile) gneiss. Drake and Morgan (1981) have indicated these "nodes" of high grade metamorphism are northern termini of a broader region in northern Virginia. East of Bear Island, the argillaceous rocks are mainly retrograded to medium and fine-grained, distinctly foliated chlorite-muscovite schists.

Metamorphosed greywackes and sub-greywackes are interbedded with the argillaceous rocks in varying proportions (called rhythmite by Cloos & Anderson, 1950). Interbedded with mica schists, the graded metagreywackes appear light gray, while the mica schists appear darker gray or black (Fig. 3). Many primary structures including laminations, slump and other chaotic soft sediment structures are remarkably well preserved despite the intense metamorphism. Graded bedding is common, with beds (Fig. 4) displaying an unlaminated base, which grades upward into a laminated base of thin micaceous layers alternating with quartz bands (Fisher, 1963).

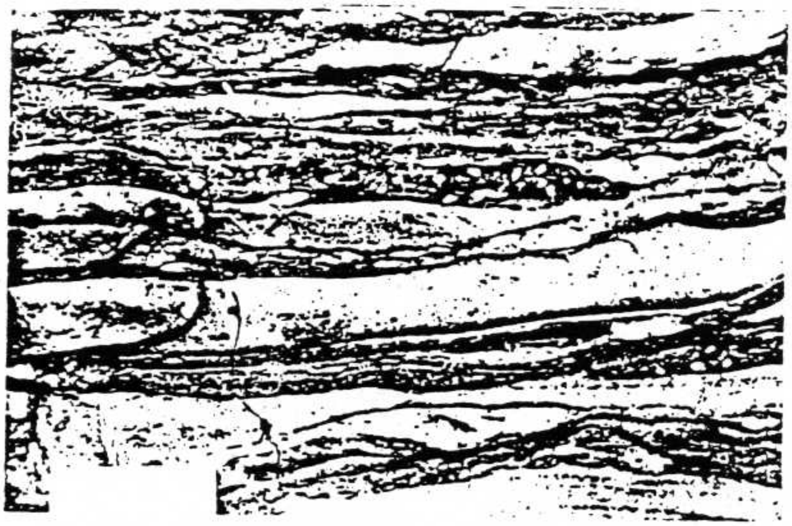


Figure 3. Interbedded metagreywacke and mica schist near the zone of intense metamorphism on Bear Island, Tormey (1988).

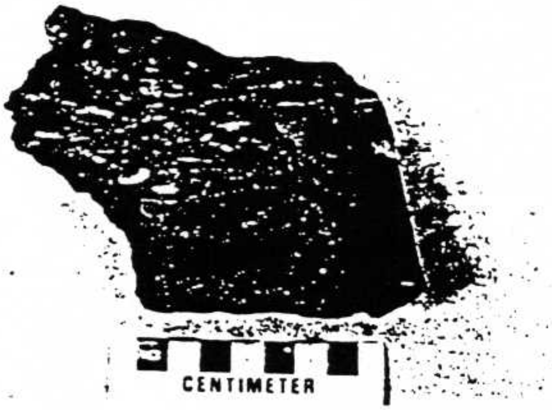


Figure 4. Graded bedding in a metagreywacke hand sample.

Amphibolite bodies occur conformably in the metagreywacke-mica schist series near the southeastern end of Bear Island, and in and near the Bear Island syncline. Smaller bodies have also been mapped near Cropley, Maryland and downstream on the Virginia river bank near Yellow Falls (Reed & Jolly, 1963) and Stubblefield Falls (Fisher, 1963, Pl. 2). The amphibolite is generally very coarse-grained and massive in the central portions of bodies, consisting of closely packed irregular clots of hornblende in a fine grain matrix.

Granodiorite dikes and plugs (Fig. 5) ranging in composition from quartz diorite to quartz monzite (with increasing alkali feldspar content) are numerous in and near the zone of highest regional metamorphism. A few cross-cutting dikes occur as far upstream as Great Falls, and as far downstream as Perry Island. These light-colored, fine-to-medium grained rocks were called the Bear Island Granodiorite (Cloos & Cooke, 1953). In Figure 6, a quartz monzite body is shown occurring on the Virginia side of the Potomac Gorge, illustrating both irregular pattern and sharp contacts with surrounding metagreywacke.

The Georgetown Plutonic Complex, also occurs as part of the crystalline series in the Falls Stretch as an extensive complex of elongate concordant intrusions separated by thin septa of older rocks cropping out intermittently between Langley Islands and Little Falls Dam, and downstream in the District of Columbia. Although this complex includes by far the largest intrusions in the area, and ranges in composition from ultramafic to granodioritic, they are mentioned here only in a cursory manner, due to their lack of apparent impact on Falls Stretch geomorphology. The four units identified by Fisher (1963, Pl.1) include: ultramafic rocks, hornblende quartz diorite, biotite quartz diorite, and Kensington Gneiss.

Although Coastal Plain sediments lie primarily southeast of the Falls Zone, locally Plio-Pleistocene counterparts extend westward up the river valleys in estuarine and/or fluvial form, capping terrace benches and isolated outliers on nearby uplands. The marked sea level fluctuations of the Pleistocene are believed to have had a profound base level effect on these portions of the Potomac Valley, more complex in fact than present geologic maps in Maryland suggest.

Only five post-Cretaceous Coastal Plain units mapped in Maryland and the District of Columbia relate to the unconsolidated sediments of the Falls Stretch. All these units need refinement and additional detailed field study. For a more complete review of Pleistocene coastal morphlolgy, see Flint (1940) and Richards (1972); Murray (1961) furnishes a more thorough discussion of Coastal Plain formations.

The Patuxent Formation is the basal Coastal Plain formation and is the only Cretaceous deposit differentiated within the study area (Arundel Clay and Patapsco Formation occur nearby in the District of Columbia). Lying directly on the crystalline basement, and thought to have been deposited as outwash from the Piedmont, it consists of a surficial layer of mixed, white or iron-stained clay.

Only the Pliocene (?) Bryn Mawr, and Brandywine gravels lap onto the Piedmont near the study area, although other Tertiary formations occur east of the District of Columbia. Wentworth (1923) and Campbell (1933) separately traced these gravels upstream along the Potomac River through the Falls Stretch; the fluvial origin of both gravels is now generally accepted. Cooke (1952)

Figure 5. Granodioritic plug flanked by darker masses of amphibolite on Bear Island, Tormey (1988).

Figure 6. Quartz monzite dike exposed along the Virginia wall of Mather Gorge below Great Falls (from Bear Island).

described the Bryn Mawr as consisting of coarse, poorly sorted pebbles in red sand and silt, and believed the bright red color distinguished it from the pink or yellow Brandywine. Both deposits have also been distinguished by their respective altitudinal relationships - the Bryn Mawr being everywhere higher.

Details of Pleistocene stratigraphy in the Falls Stretch have been vague, poorly defined, and at variance with findings of others working elsewhere on the Atlantic Coastal Plain. Prior to Tormey's (1980) study, only three formational units had been indicated - the Sunderland, the Wicomico, and the Pamlico Formations (Fig. 7).

Up to the present time the Sunderland Formation has largely remained undifferentiated as "terrace deposits" within the Falls Stretch, even though outcrops in the southeastern District of Columbia were mapped by previous workers (Cloos & Cooke 1951, 1953). Darton (1947) also included much of the Sunderland in his Pleistocene "river terrace" deposits. Where the formation has been identified, it was mapped between the 220 and 100 ft. contours and described as coarse gravel, crossbedded sand silt and clay, with color ranging from orange-red to pink, yellow and blue-gray. Significantly, large striated boulders and cobbles, thought to be ice-rafted (Wentworth, 1930), have been observed near the lower boundary by several writers. The Sunderland is regarded as largely pre-glacial Pleistocene (Tormey 1980, 1988).

Both the Wicomico Formation and the Pamlico Formation mapped by Cloos & Cooke (1951, 1953) in Washington, D. C. and Maryland have been described by characteristics too loosely defined and altitudinal limits too generalized, to reveal details of the Pleistocene eustatic record. The Wicomico, mapped by Cloos and Cooke (1951, 1953), has been described as a coarse gravel bed at the base, and fine sand and silt above, with local clay lenses and has been mapped encompassing materials between 25 and 140 ft. above sea level. In Virginia, Darton (1947) included the Wicomico in his undifferentiated Pleistocene "river terrace deposits." The Pamlico, also mapped by Cloos and Cook (1951, 1953) in even greater degree of generalization was indicated as encompassing all deposits between 25 ft. and present sea level (including both Recent and alluvial deposits).

THE PEDOLOGIC SETTING

Soils along the Falls Stretch have been mapped and described by the Soil Conservation Service (Mathews, Compy, & Johnson, 1961; Porter, et al., 1963; Smith, 1976). Pertinent map units have been grouped (Plate 2) into six categories principally according to origin based upon Soil Conservation Service (SCS) description: Floodplain, Low Terrace, High Terrace, Miscellaneous Outwash Gravel and Loessal Deposits, Residuum, and Rocky Land, Udorthents, Made Land and Urban Land.

Floodplain soils occur principally in two catena: the Melvin-Lindside-Huntington, primarily along the trunk channel and the Wehadkee-Chewacla mapped less frequently along tributaries (Froelich, 1974b). In Virginia, these soils have not always been differentiated and have been mapped in some areas as mixed alluvial land consisting of recent mixed alluvium, chiefly brown in color, fine textured, washed from soils of the uplands and

Maryland[a]				Southern A.C.P.[b] (Va. through Fla.)				
Age	Terrace	Elevation of terrace formation		Elevation of strandline		Terrace	Scarp	Age
Pleistocene	Talbot (Pamlico on some maps)	10-45	3.0-13.7	10	3.0	**Silver Bluff**	**?**	**Pleistocene**
				15	4.6	**Princess Anne**	**?**	
				25	7.6	**Pamlico**	**Suffolk**	
				45	13.7	**Talbot**	**Walterboro**	
	Wicomico	45-90	13.7-27.5	70	21.4	**Penholoway**	**Summerfield**	
				100	30.5	**Wicomico**	**Surry**	
?	Sunderland	90-200	27.5-61.0	120	36.6	**Sunderland**	**Orangeburg**	
Plio-cene	Brandywine	200-400	61.0-122.0	215-270	65.6-82.4	Citronelle (warped markedly)		**Pliocene**
	Bryn Mawr	> 400 FT	> 122.0 M	FT	M			

Figure 7. Comparison of coastal terrace (terrace formations) mapped in Maryland and other states of the southern Atlantic Coastal Plain. Modified after:
[a] Cloos and Cook (1951), Cloos and Cook (1953).
[b] Richards (1962), Doering (1960), Tormey (1980).

lodged on first bottoms. In the District of Columbia, the Codorus soils occur along floodplains of Rock Creek and Battery Kemble Park Branch.

The Melvin-Lindside-Huntington catena ranges from dark grayish brown (10YR 3/3) in color in the profile. The topographically lowest, and therefore frequently flooded, Melvin soils are so poorly drained that these soils are distinctly mottled nearly to the surface. They occur at or near the level of the annual flood. In contrast, the deep well-drained Huntington soils lie topographically above the annual flood, occurring as narrow terraces on highest parts of bottom-lands. As deposits of Recent alluvium, derived principally from sedimentary rocks, soils of this catena are weakly modified by soil forming processes, having little contrast in color and texture throughout the profile.

The Wehadkee-Chewacla catena ranges from dark grayish brown (10YR 4/2) to brownish-gray (10YR 6/2) in deeper horizons with distinct mottles of yellowish-red (5YR 4/6) appearing quite near the surface, and mottling or gleization of the subsoil. Wehadkee soils are topographically lowest, poorly drained, and more frequently flooded, especially after spring rains or thaws. Both soils are young and may receive fresh sediments mainly from the crystalline Piedmont upland after each flood, with many places subject to the annual flood. Typically, there is little if any horizonation.

Low terrace soils have been mapped in two units by the SCS and are a source of confusion. Along the trunk channel in Montgomery County, MD, the Ashton soil

is distinct. This unit has not been identified by SCS in Virginia and in Washington, D. C. Absence (apparent or otherwise), in Virginia may be attributed to effects of lateral migration of the river and minimal opportunity for extensive areal development. Distinction of low terrace soil in the District of Columbia or its possible relation to the Ashton map unit has not been made. Also, the other low terrace soil - Wickham - is used by SCS to indicate young low terraces along Potomac tributaries in Virginia, and deep soils on high terraces along the trunk channel in Maryland.

Ashton soils are dark grayish-brown (10YR4/2) to reddish-brown (5YR 4/4), and dark brown (7.5YR 4/4) in deeper horizons with subsoil less red than described in many places. Well drained, and seldom wet for long periods, these soils are above the level of the hundred-year flood. The surface is a silt loam grading to silty-clay loam with gravelly silty clay loam at depth. They have a weak textural B-horizon. Developed from old alluvium derived from sedimentary rocks, they contain few rounded gravel fragments; gravel is mostly chert, but in some places contains sandstones.

Wickham soils (mapped as an undifferentiated unit in Fairfax County, VA, Porter et al., 1963) are brown to dark brown near the surface and yellowish-brown to reddish brown, and strong brown lower in the profile. They are deep and well drained, occurring on low terraces slightly elevated above floodplains along Difficult Run and Occoquan Creek in widely separated areas. Formed in moderately young alluvium, they exhibit strong profile development and consist of material derived from Piedmont land.

High terrace soils occur in two catena: the Roanoke-Wickham forming from mica schist on the High Piedmont, and the Captina-Elk, originally from soils on sedimentary rocks. Both catena are distributed primarily along the trunk channel.

The Roanoke-Wickham catena ranges from very dark grayish-brown (2.5YR 3/2) to light olive gray (5Y 6/2), and dark gray (5Y 4/1) with dark reddish-brown (5YR 3/3) mottles in the poorly drained Roanoke soils, to dark brown (7.5YR 4/4), yellowish-red (5Y 4/8), and red (2.5YR 4/8) in the deep well-drained Wickham soils. This catena developed from very old alluvium; the Roanoke appearing to have partially developed from sedimentary rocks in addition to its crystalline component. A fragipan in the Roanoke accounts for its poorer drainage.

The Elk-Captina catena ranges from dark yellowish-brown (10YR 4/4) at the surface, to brown (7.5YR 5/8) or yellowish-red (5YR 4/8) in Elk soils, and dark yellowish-brown (10YR 4/3) or yellowish-brown (10YR 5/4) in Captina soils. Both soils are distinctly mottled in lower horizons. Though Elk soils are deep and well drained, Captina are only moderately well drained, since they have a distinct fragipan. Derived from old alluvium from areas of sedimentary rock, the catena lies above the level of the hundred-year flood.

The miscellaneous outwash gravel and loessal deposits are another group of three soil associations in an apparent catena relationship. Only the Beltsville soil occurs in the Falls Stretch.

Beltsville soils are very dark gray (10YR 3/1) or yellow (2.5Y 8/6), grading to brownish-yellow (10YR 6/6), and very pale brown (10YR 7/3) lower in

the profile. Described in Maryland as well drained, and somewhat poorly to moderately well drained in Virginia, they have a highly developed fragipan and mottled subsoil. Occurring in high old fluvial terraces along the trunk channel of the Potomac on micaceous quartz schists, small areas have rounded gravel on the surface and throughout the solum. Small areas of Captina are also included in this unit (since Captina was not mapped in Fairfax County).

Residual soils significant in the Falls Stretch are found in two catena: Manor-Glenelg, and, the Aldino-Calvert-Conowingo-Chrome association. Both associations occur on the Piedmont upland, with the Manor-Glenelg having the widest distribution, formed from weathered schist; the Aldino-Calvert-Conowingo-Chrome association is a group of shallow soils developed from weathered serpentine, and is characterized by a distinct fragipan and generally poor drainage.

Rocky land, udorthents, made land and urban land are essentially part of the thinly mantled rocky surface of the Piedmont plateau that slopes to the Coastal Plain or, areas of fill or, soil so disturbed by human activity, that examination and detailed identification of soils and soil-like material is impractical. In Maryland, the rock land classification has been perhaps too generously applied to the bedrock islands and bluffs along the Potomac.

THE RIVER AND ITS FLOW REGIME

The Potomac River basin is part of the Atlantic slope drainage lying partially within the states of Pennsylvania, Maryland, West Virginia, and Virginia. Between the Allegheny Front and the Blue Ridge, the Potomac basin is oval shaped. As a consequence of the great length of its southern tributaries, the trunk channel (the North Branch) crosses the northern part of the basin and leaves the oval at its eastern corner. There, the trunk stream and tributaries funnel across the Piedmont toward the Chesapeake Bay. The basin forms a drainage area of 14,670 square miles, 11,760 square miles of which lies upstream from Washington.

Annual precipitation in the basin ranges from 35 inches in the drier Appalachian Plateau rain shadow in the Ridge and Valley zone, to between 40 and 45 inches over the rest of the basin with higher elevations receiving up to 60 inches (USWB, 1968 USGS, 1974). Precipitation is well distributed seasonally with approximately 4 inches monthly in summer, and up to 3 inches in each winter month. Despite the slight summer maximum, this is the season when droughts are most frequent. Summer precipitation is principally due to scattered thunderstorm activity and tropical hurricanes traveling along the coast; these are less dependable than frontal storms and extra-tropical cyclones of less intensity, but longer duration, in the cooler half-year (Dalrymple, 1965).

The only permanent gaging station on the Potomac within the Falls Stretch (6465) is on the left bank upstream one mile from the District of Columbia boundary line. The average discharge according to the 40 year record was approximately 10,640 cubic feet per second (cfs). During the 1930-70 record, flows as low as 601 cfs (includes diversion of 489 cfs for municipal use) and as high as 484,000 cfs (1936 flood) have been recorded (Darling, 1962). The average flow is equalled or exceeded approximately 30% of the time.

Hoyt and Langbein (1955) have made a generalized map of the United States showing when floods are most likely to occur; the Potomac falls within the winter season on this map. In Carter's (1966) map focusing on the Potomac basin, (Fig. 8) it is interesting to note that, while the major portion of the basin is subject to a seasonal flood type with a spring concentration, there are distinct exceptions which complicate the movement of a flood crest through the basin.

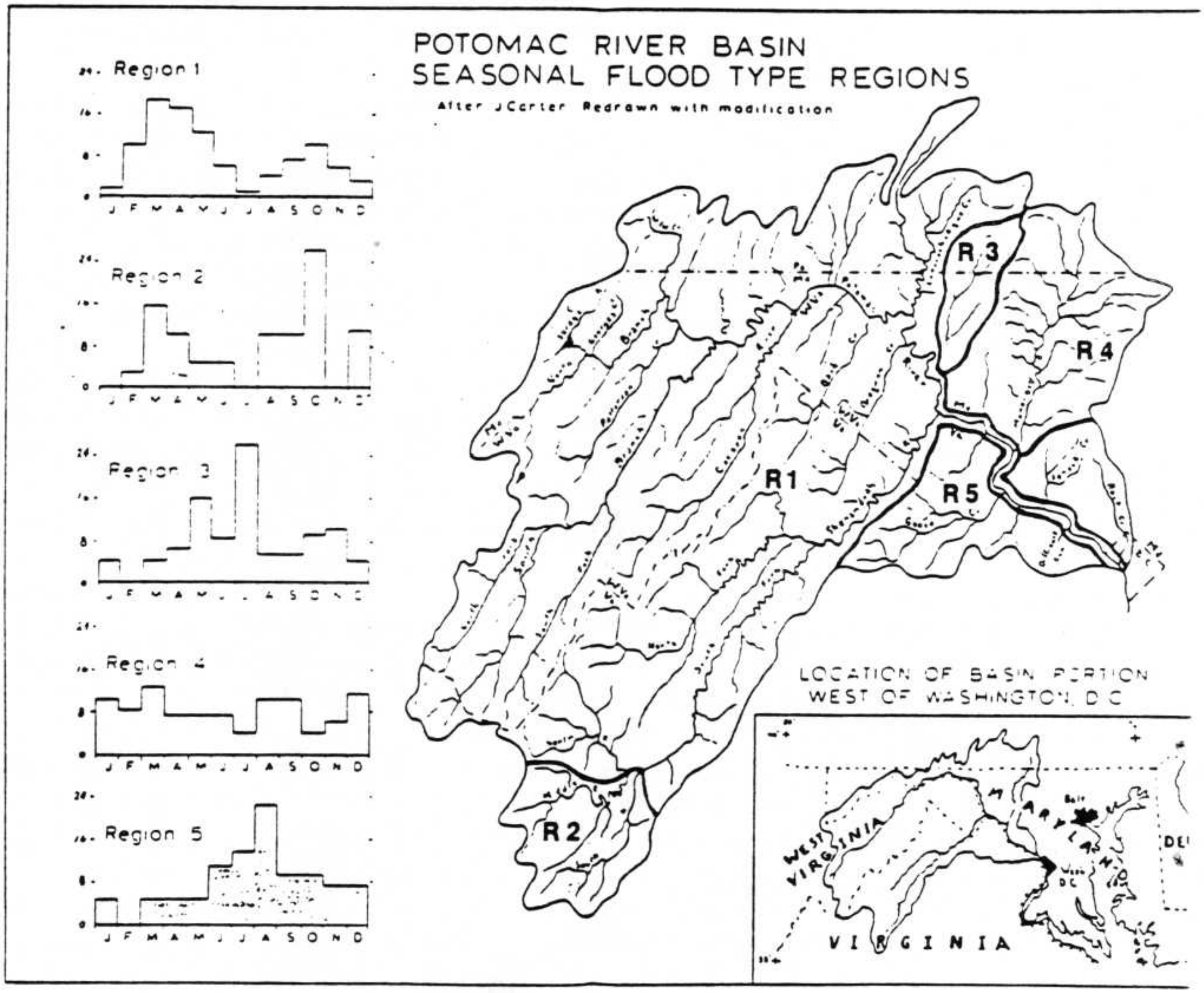


Figure 8. Potomac River basin seasonal flood type regions (modified after Carter (1966).

Although Potomac floods have occurred in almost every month, higher stages tend to occur in late winter or early spring due to increased runoff, caused by the dual influence of temperature, on stored water in the drainage basin (snow and ice), and the reduced infiltration capacity of frozen soil. Similarly, temperatures played a significant role in causing the March, 1936 flood. That year, winter temperatures remained below freezing with no considerable thawing period; an increase in temperature during the last few days of the month caused a break-up of ice which had covered channels up to that time. High stages, resulting in many places from ice jams were recorded at all river gaging stations. Based upon USGS flood-probability charts, this flood has a recurrence interval of 100 years; stream gaging records and historical records reveal this was the largest flood since 1733; however, the flood in 1889 was of comparable magnitude.

Reconstructed profiles of the 1936 flood crest indicate that above Great Falls, where the channel is wide, the flood was only 10 feet higher than the drought stage in 1930, but below Great Falls, in the gorge where the channel has a smaller cross-section, the flood crest was 80 feet higher than the drought stage. Figure 9 illustrates high and low flow conditions at Olmstead Island, MD.

In alluvial channels, the commonly accepted maximum depth of scour equals 2.5 times the rise in the water surface (Lane & Borland, 1954; Lattman, 1969), although scour is not directly related to the velocity of stream flow, but interdependent with type of bedload and rate of upstream sediment supply, as well as configuration of the bed. This generalization is useful insofar as it gives theoretical magnitude of scour possible during hundred-year floods, or past meltwaters of similar magnitude. At this rate, a river in an alluvial channel having an annual peak of 25 feet above the normal water surface (one-half the rise of the hundred-year flood of the Potomac) might, under ideal conditions, vertically cut and refill approximately 60 feet of its alluvium in a reach segment during passage of one flood (scour of greater magnitude has been observed at several river sections along the Colorado River and the Rio Grande; Leopold, Wolman & Miller, 1964). Although scour of this magnitude is less typical in humid areas at the present time, due to coarsening of the bed by perennial flow, conditions in the late-glacial - early interglacials would have been similar to the spring snowmelts of western rivers. In channels having thin alluvial beds composed of small and medium particle sizes, the bedrock floor must be repeatedly exposed to severe abrasion and erosion.

After the 1972 flood, I observed several severely scoured reaches (vegetated floodplain cut to bedrock with trees having trunk diameters greater than one foot in diameter uprooted). See Figure 10. Snow-melt floods, resulting from heavy snowfalls in the Appalachians during glacial periods, must have periodically stripped the bedrock floor, down cutting through time, in saw-like cuts similar to present flood cycles.

GEOMORPHOLOGIC DEVELOPMENT OF THE FALLS STRETCH

Surficial deposits and morphology of the river valley along the trunk channel of the Falls Stretch between Theodore Roosevelt Island and Seneca, Maryland have been mapped in detail (Tormey, 1980). Through a regional classification of geomorphic forms, this study indicated that the Falls Stretch

Figure 9. A. & B. High and low flow conditions at Olmstead Island, Maryland near Great Falls (Tormey, 1980).

Figure 10. Flood scoured reach near the downstream end of Bear Island, Maryland after the 1972 Agnes Flood (Tormey, 1980).

of the Potomac River developed during the Pleistocene fluctuations of sea level. It extended the Surry Scarp in its probable estuarine phase into the present Falls Stretch and also suggested that <u>other</u> scarps (Orangeburg, Walterboro, and Suffolk, etc.) mapped elsewhere on the coastal plain, occur in the Falls Stretch. This study further implied that knickpoints in the Potomac and its Fall Zone tributaries reflect the sea level fluctuations. It also shed new light on conflicting interpretations in published geologic and soil mapping of Pleistocene and Holocene deposits in the Falls Stretch, and through multivariate factor analysis, identified soil and sediment parameters of value in delineating the modern floodplain from older deposits of a river subject to large-interval major flood events.

Highlights of the local area's geomorphology are indicated here, to further illustrate the exceptional value of the Falls Stretch of the Potomac in both instructional and research field activity. For specific details, refer to the original report noted above. Maps detailing the geomorphic development of the Potomac River Falls Stretch (Plates 3-7) are available from the author at cost.

Interpretation of the data collected on surficial deposits and morphology indicates the valley is divisible into several distinct morphologic forms. These include (1) the modern floodplain, (2) fluvio-estuarine terraces, (3) alluvial fans, (4) active and inactive channels.

The floodplain (1) is composed of stratified sand, silt and clay deposited on coarse deposits of lag gravel. Sand textures vary considerably from one site to the next in the Falls Stretch. All size grades may be found, ranging from coarse sand deposited in abandoned plunge pools along Bear Island Gorge where the stream velocities are high, to fine silt and clay in the wider reaches near Cabin John Island, Maryland. Sand beds frequently display crossbedding and tend to become somewhat stabilized rapidly by the growth of willow shoots deposited pari passu.

The floodplain varies from a broad undulating surface 600 feet wide in the upstream vicinity of Little Falls, to local, flat pocket-like development in the former plunge pool basins along Bear Island. Width of the floodplain increases downstream toward Great Falls Dam and Little Falls Dam, as might be expected; the floodplain also widens downstream from Little Falls as a result of reduced stream gradient and the tides.

Terraces (2), remnants of six different stages of alluviation, occur in the Falls Stretch; five of these are partially estuarine terraces formed in response to periglacial conditions in the Potomac Basin. The terraces are paired. Their scarps have essentially constant toe elevations (varying only slightly), largely due to their mode of formation in response to former sea levels. Where toe elevations <u>do</u> vary, these minor discrepancies can be attributed to sporadic Recent floodplain deposition where man-made dams have altered the river gradient, or to colluvial wash and deposition. The terraces are better developed on the Maryland side of the Potomac, since the river has tended to migrate toward the southeast in the direction of regional slope. However a majority of the terraces are well preserved and have relatively flat horizontal upper surfaces (0-3% slopes), except where cut by anastamosed channels. In areas where terraces have not been mapped, correlaton of terrace toe elevations and tributary knickpoints support the concept of continuity and paired origin.

All the terraces are composed of alluvium similar in composition, but coarser in texture than sediments forming the modern floodplain. Higher, older terraces have better developed soil profiles and a mantle of silt having reddish-brown color, whereas in younger terraces, the silt has a grayish-brown color. In other instances, soils are masked by colluvial slope wash and colluvial rubble from adjacent slopes. Where low terraces have been inundated by Recent floods, there is a noticeable increase in soil stickiness in the A horizon.

The Sunderland terrace scarp has a toe elevation near 120 feet. It may be observed via stereo air photographs and topographic maps from the vicinity of Sheridan Circle in Washington, D.C., to Bear Island. Along this segment of the Maryland bank, the terrace is subparallel with the lower terraces for nearly 12 miles before merging with the irregular crystalline surface. Not well preserved along the Potomac in Virginia, it occurs primarily as valley fill in higher order tributary streams. On the Maryland side, the Sunderland scarp has an irregular pocket-like morphologic development in abandoned plunge pool basins of Little Falls Branch (at the foot of the largest of these basins, Arizona Avenue intersects with Canal Road). On the upstream bank of the mouth of Little Falls Branch, the terrace has a penninsular form. Both the penninsular and abandoned plunge-basin form is repeated near Cabin John (third order) and Rock Run (second order). As alluvial deposits thin upstream, the configuration alters from the essentially continuous-subparallel form, to patchy development capping larger islands and higher bedrock remnants before merging with the irregular bedrock bench surface of Bear Island between 120 and 130 feet.

Near Little Falls an exposure of Sunderland gravel has been described as consisting of 3 feet of well-oxidized silty clay overlying a foot thick layer of gravel coarse fragments varying from quartz gravel less than 1 inch in diameter to oblong sandstone boulders as large as 2 feet; the gravel overlies a mottled silty clay which rests on well oxidized and weathered Sykesville.

The Wicomico terrace is considerably less well-preserved in the lower reaches of the Falls Stretch than elsewhere on the Coastal Plain. Less than 75 feet wide in many places, it is fragmented on both banks by colluvial wash and deposition: in Virginia, the Potomac has undercut the slope, while in Maryland construction of the George Washington Memorial Parkway makes photo interpretation and field correlation tenuous. Despite these difficulties, and the fact that the terrace at least partially composite in the upper reaches, it may be followed upstream approximately 12 miles from Theodore Roosevelt Island.

Between the mouths of Cabin John Creek and Rock Run, the Wicomico occurs in abandoned plunge pools apparently cut earlier by Rock Run (Fig. 11). At Rock Run and in the area near Stubblefield Falls, the terrace has its widest development in the form of broad valley fills and alluvial fans as much as 700 feet wide. From Vaso and Turkey Islands, upstream to the vicinity of Bear Island, Wicomico alluvium is increasingly overlapped by Recent (and probable Pleistocene) flood levels resulting in thinning of the alluvial cover. Near Lock 8, cross-bedded Wicomico gravel is exposed over an outcrop of well-weathered Sykesville formation. The gravel is ironstained, poorly sorted, with sizes ranging from 1.0 inches, to cobbles 1.0 feet in diameter in a buff-orange matrix.

The Penholoway terrace scarp has been tenuously mapped 5 miles downstream

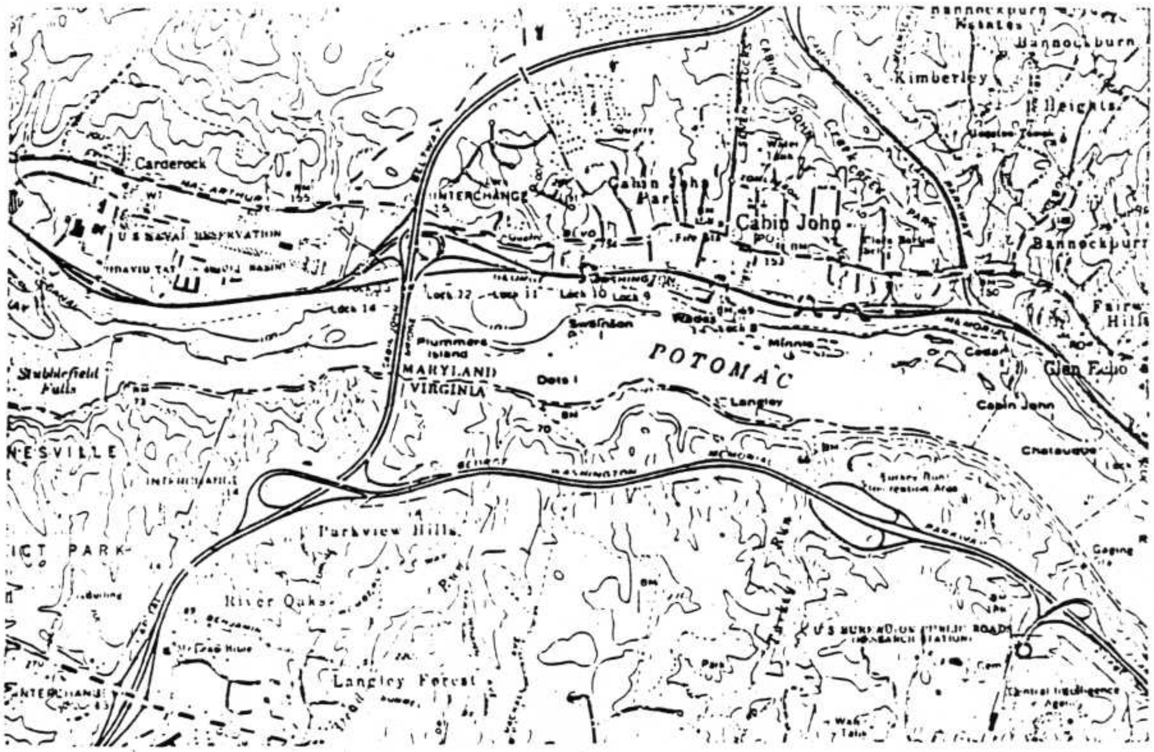


Figure 11. Abandoned plunge pools between the mouths of Cabin John Creek and Rock Run, Maryland, as indicated on a portion of the Falls Church, Virginia-Maryland quadrangle, 7.5 minute (Tormey, 1980).

from Little Falls Dam with almost deceptive regularity on the Maryland side of the river. Both the Chesapeake and Ohio Canal and the George Washington Memorial Parkway lie on the tread of this terrace - bench at least part of the distance. Although weathering of deposits suggests a Penholoway age on the terrace surface, definitive identification of the toe of the scarp is nearly impossible in some locations due to the construction. In the lower reaches, the terrace is typically better preserved on the Maryland shore where it maintains a near-constant width of 500 feet; in Virginia, the terrace is best preserved as dissected alluvial fills and valley fill in Donaldson and Pimit Runs. On the Maryland bank, the terrace attained maximum development in the Falls Stretch as part of a coalesced alluvial fan between Cabin John Creek (third order) and (second order) Minnehaha Branch. Built up by Talbot and successive floods, the fan is dissected now forming Cedar, Cabin John and Chautauqua Islands.

Penholoway deposits were observed near Fletcher's Cove, occuring as iron-stained gravel with a buff-orange silt loam matrix on a weathered outcrop of Sykesville formation. Penholoway gravels were also observed near Chain Bridge where several striated cobbles were found.

The Talbot terrace lies above the level of Recent floods along the lower three miles of the Falls Stretch. In Virginia, the terrace occurs primarily as alluvial fans near the mouths of first order tributaries and as valley fill in Donaldson Run, a second order tributary. In Maryland, the terrace parallels the river, narrowing gradually from a width near 500 feet at Georgetown Reservoir on the Potomac. Although the scarp toe may be traced upstream to High Island near Chain Bridge, the terrace there is represented by a bedrock bench subject to Recent floods and deposition.

The Pamlico terrace forms an almost continuous scarp (25-30 foot toe) on both sides of the river upstream to High Island (5 miles) except for two short breaks on the steepened Virginia shore where the terrace is preserved only at the mouths of tributary streams. Upstream from Donaldson Run, the terrace is composite on both sides of the river: in this reach, floods of Recent and also Princess Anne (?) stage flowed at levels high enough to top at least part of the Pamlico terraces. The terrace gradually increases in width from 500 feet, as it merges with Recent deposits on an irregular bench cut at a slightly lower level. Approximately 0.5 miles downstream from Chain Bridge, the Recent deposits thin and the linear channel cuts become longer, wider and more sharply defined, indicating a more active attack on the bench surface (Fig. 12).

The Princess Anne terrace is incomplete in the Falls Stretch in the sense that a scarp's toe (15 feet elevation) may be traced upstream only 4 miles from Theodore Roosevelt Island. The terrace lies below the level of the hundred-year flood and is mantled by Recent deposits. Upstream from Gulf Branch the terrace is represented by an exposed bedrock bench with occasional caps of alluvium. The alluvium is less than 10 feet thick, and in most places consists of brown clayey silt. Although the scarp may be traced almost continuously along both sides of the river, in Virginia evidence is best preserved near the mouths of tributaries. At Fletcher's Cove (on the Maryland side), deformed vegetation indicates the hundred-year flood topped the outer edges of this terrace by approximately 3 to 6 feet.

Alluvial fan (3) deposits of early Pleistocene age with well-developed profiles and well-weathered clasts were identified upstream from Great Falls near Nichols Run (second order). Two other alluvial fans mapped in the Falls Stretch are believed to be primarily possible late-Pleistocene age, although somewhat modified and dissected by Holocene floods. These fans were mapped near the mouths of Rock Run (second order) and Minnehaha Branch-Cabin John Creek (second and third order). Although other fans may have developed on streams of similar order in the Falls Stretch, they are nowhere as well preserved as at the mouth of these tributaries on the Maryland bank of the river.

The largest of the fans is actually an aggregate of fan deposits from both Cabin John Creek and Minnehaha Branch, which coalesced and then were later dissected (forming Cedar, Cabin John and Chautauqua Islands) and terraced along the trunk channel border. Absence of sandstones and chert from the western Potomac basin clearly indicates the sources of gravel and cobbles are local and therefore derived from tributary basins; the gravel beds also slope gradually toward the trunk stream.

Channels (4) viewed from the air, indicate the flow of the Potomac follows a pattern of alternate reaches of trunk and multiple anastamosing channel form. This form has historically been associated with the Falls Stretch, at least

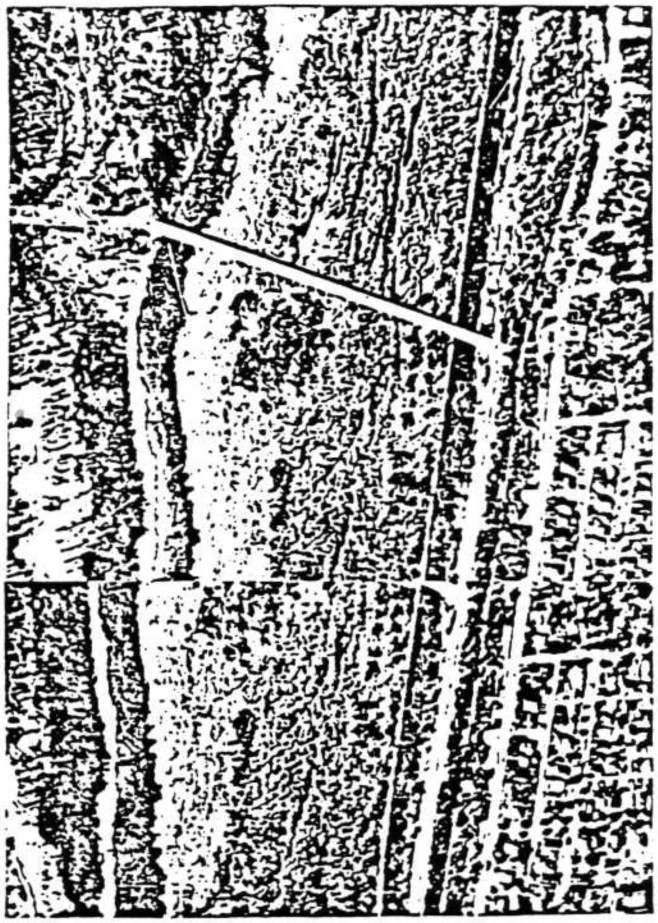


Figure 12. Broad alluvial channels may be observed between topographically higher terrace outliers downstream from Chain Bridge, Maryland. Channel scar lakes occur upstream from Chain Bridge.

since the late Pleistocene. On first consideration, this form of drainage might seem accidental; however, such is <u>not</u> the case. Like the terraces and alluvial fans, the channels also provide evidence supporting general migration of the Potomac toward the Virginia bank.

Beyond the intermediate reaches of falls and rapids, the trunk channel of the Potomac is characterized by three kinds of channel form in the Falls Stretch: tidal, braided or anastamosing, and gorge; only the latter two are discussed here. The criterion used to separate the primarily active from the primarily inactive channels in the Falls Stretch is the level of the hundred-year flood. According to this classification, inactive channels occur above the hundred-year floodplain; active channels occur below the hundred-year floodplain. Note - under this system, an active channel may or <u>may not</u> have actively flowing water in it at the present time.

The alluvial braided trunk channel occurs principally in two areas - between Blockhouse Point and Great Falls Dam, and between Dots Island and Little Falls Dam. In both areas, the river gradient is slight and the cumulative channel width is greater than the channel width immediately downstream.

At Blockhouse Point, the trunk channel is about 1,400 feet wide. One-half mile downstream is the head of Watkins Island. This channel-scarred alluvial island forms the primary mid-channel divide for approximately 3.5 miles. Accompanied by smaller alluvial islands, varying considerably in size and frequency, the exact number and width of channels varies from reach to reach. Smaller islands tend to have an elongated tear shape, similar in form to the pattern noted by Leopold and Wolman (1957), in their flume experiments; larger channel islands vary from this pattern, but outlines of old channels (identifiable by vegetation patterns) suggest an aggradation and growth from the basic form.

Downstream, accompanying the adjustment in width-depth ratio, tear-shaped alluvial channel islands, similar to those discussed above, have formed between Dots and Little Falls Dam. Unlike their counterparts above Great Falls, these channel islands tend to agglomerate near the Maryland bank. Although formation of the islands nearer the Maryland shore may be partially due to deposition in the Potomac channel by Rock Run and Cabin John Creek tributaries, lateral channel shifting toward Virginia during downcutting between Great Falls and sea level is strongly supported by trunk channel form.

The gorge adjacent to Bear Island extends 0.75 miles downstream from Rocky Islands to the mouth of Difficult Run, where the channel widens, alters its course almost 90°, and parallels the strike of bedding shistosity along the limb of a small anticline. For more than half its length below Rocky Islands, the channel is straight, narrow and steep-walled. Along this reach, Fisher (1963) inferred the presence of a fault having unknown dip and striking S 30° E. The channel leaves the inferred fault parallel to a joint system striking S 90° E and dipping 65° (Fig. 13).

Excepting approximately a half dozen reaches, the trunk channel has a width less than 1,000 feet in the Falls Stretch. In each of these cases, the widened upstream reach is related to a knickpoint downstream (i.e., Yellow Falls and Stubblefield Falls) or a combination of dam and knickpoint (i.e., Great Falls and Little Falls. In the Falls Stretch, the Potomac is primarily banked by flights of the fluvio-estuarine terraces; however, the trunk stream narrows between bedrock walls to less than 100 feet in only two places - downstream from Little Falls and Great Falls.

The anastamosing channels below the hundred-year flood level are flood channels occupied by the river during flood stages. Located mainly along the slip-off slope near Little Falls, Cabin John-Glen Echo, and Great Falls, at a variety of levels (near the water surface to as much as 40 feet above the normal water level), these channels are largely of Holocene age, formed by Holocene floods of varying magnitude. The channels include two types: alluvial and rock-defended. Where mantled with sediment, thicknesses of floodplain deposits vary between 0 and 30 feet. Bedload deposits in channels nearer the trunk stream and topographically lower, have deposits coarser (cobbles, gravel, sand) than do more distant slackwater channels (silt, clay). The best developed broad alluvial channels occur between topographically higher terrace outliers

Figure 13. Aerial view of the steep-walled section of Bear Island Gorge (Mather Gorge) striking S. 30° E. (inferred fault) at the point where the channel shifts direction parallel to S. 80° E., a local joint direction (Tormey, 1980).

downstream from Chain Bridge, Maryland. Although there is some indication of structural control of channel orientation, a greater thickness of the alluvial cover decreases the effect of bedrock on channel direction.

The rock-defended anastamosing channels on Falls Island have a gradual slope near the head of the island (and Great Falls) and a sharply increased slope below the falls. The braiding channels form a network of bedrock-defended, steepened reaches marked by small waterfalls or rapids as the mean water surface falls 70 feet over the 2,500-foot-long island. No more than 100 feet at their widest point and commonly less than 20 feet wide, the channels roughly parallel the strike of the bedding schistosity in the interbedded facies of Wissihickon Formation. The process of anastamosis is clearly exemplified on the Maryland shore near the old bridge to Falls Island. At this site, the closest channel (left side looking downstream), looses a portion of its flow to farther channel and in the process attacks the thin intervening wall. Both the near and the far channels, as well as the anastamosing channel, parallel local joint directions. Active erosion and periodic flushing of the channels is evidenced by fresh rock surfaces, the general absence of fine grain sediment, and the wide variations of flow observed in the reaches. In the interfluve areas, alluvium forms a thin cover in depressions and potholes on the irregular surface; this supports a meager population of dwarfed trees marred by flood damage near the head of the island, but decreases both in distribution and thickness downstream due to the steep local gradient of the trunk stream.

The inactive channels are "fossil" anastamosed channels higher than the hundred-year flood level of the Potomac. These Pleistocene remnants occur principally on Bear Island and the larger bedrock islands in the trunk channel (including Vaso, Turkey, and Offut Islands). The channels are everywhere rock-defended but are floored by varying thicknesses of alluvium consisting of gravel and sandy silt. Channels developed on the trunk stream islands are wider and deeper than on Bear Island. In Vaso Island, local fossil channel depth varies between 20 and 30 feet with broad terrace-bench interfluve areas. Although channels on Bear Island have lower local relief (6-10 feet), they have a wider distribution. The island is literally laced by a network of .the abandoned channels. Local relief is less than 10 feet over most of the island interior, but depth of dissection in the channels increases near the trunk channel to two or three times this figure, as the channels drop into plunge pool basins along the southeastern perimeter. As alluvium thickens eastward toward the interior of the island, the channel floors become less uneven underfoot. Rocky, narrow, angular floors become broad, gradual, linear depressions between irregular bedrock outcrops (channel walls). In some of these depressions, surface water collects in intermittent ponds of stagnant water. In others, a spongy mat of shrubs and herbaceous plant roots covers near-climax bogs.

When depicted in a rose diagram, anastamosed channels on Bear Island give the graph its southeastern emphasis, accounting for the greatest cumulative channel development, striking S. 5° E., S. 15° E. and S. 42° E. Channels on Sherwin Island primarily strike S. 67° E., while Vaso and Turkey Islands give development in the southwestern quadrant minor emphasis, with strikes of S. 68° W. and S. 5° W. respectively.

Effects of Important Factors on the Geomorphic Development of the Falls Stretch

Several factors have had a marked influence of the development of the Falls Stretch. These include eustatic fluctuation of sea level, regional macrostructure, and structural control according to local joint sets and other structural lineations and the effects of sedimentation and pedogenesis. Other factors more difficult to access are discussed in Tormey, (1980).

The effects of Pleistocene transgressions and regressions are evidenced principally in the formation of flights of sub-parallel terraces, formation and retreat of knickpoints on the trunk stream and associated retreat on tributaries in the Falls Stretch.

Scarps of six terraces have been mapped in the Falls Stretch. These terraces have toe elevations similar to marine terraces noted elsewhere on the coastal plain (Fig. 14). Due to their relatively constant toe elevations and sub-parallel nature, five of the terraces are believed to be of fluvio-estuarine origin, while the sixth is at least minimally estuarine. Built during the high stillstands, these terraces formed due to alluviation accompanying the rise in base level. During low stillstands, incision, potholing and knickpoint development resulted from lower base level. Elevations of knickpoints forming the major falls and rapid zones of the trunk channel at Great Falls, Yellow Falls, Stubblefield Falls and Little Falls are mimicked on tributaty streams. These knickpoints coinside with toe elevations marking terrace scarps. The two aspects of converging evidence indicate eustasy as a dominant regional control upon the drainage development of the Fall Zone.

Age	Terrace - Bedrock Bench	Elevation Toe of Scarp	
Recent	Floodplain	p.w.l.	
Pleistocene	Princess Anne	15	3.0
	Pamlico	25-30	7.6-9.2
	Talbot	45	13.7
	Penholoway	70	21.4
	Wicomico	100	30.5
?	Sunderland	120	36.6
Piocene	Brandywine & Bryn Mawr	?	
		FT	M

Figure 14. Probable age correlations of the Potomac River Falls Stretch (Tormey, 1980, 1988).

The Effects of Retreating Falls Upon the Tributaries

Profiles of over thirty tributaries occuring in the falls reaches of the Potomac between Theodore Roosevelt Island and Beall's Island show that a marked change in drainage development took place during the Pleistocene (Fig. 15). Tributaries above Great Falls show little or no response to the ice age sea level fluctuations - largely due to control by local base level - the head of Great Falls; they have a much more gentle gradually decreasing slope and knickpoints are clearly absent. This is particularly true when first order Potomac tributaries are examined. Tributaries downstream from the Falls, however, reflect base level control associated with temporary stillstands of the sea, displaying a greater number of knickpoints and a general steepening in the slope of their lower courses.

If the tributaries and knickpoints are examined graphically, several generalizations for the Potomac Falls Stretch may be made:

1. First order tributary streams consistently reflect greater frequency of knickpoint preservation than other orders when grouped by order;

2. Knickpoints on all streams show a marked tendency to match published high sea levels at least since the pre-glacial Pleistocene;

3. Although the Sykesville Formation has the greatest frequency of strea occurrence in the graph, this is largely caused by regional location of the sample (examination of water-bearing range in yield in each of the crystalline

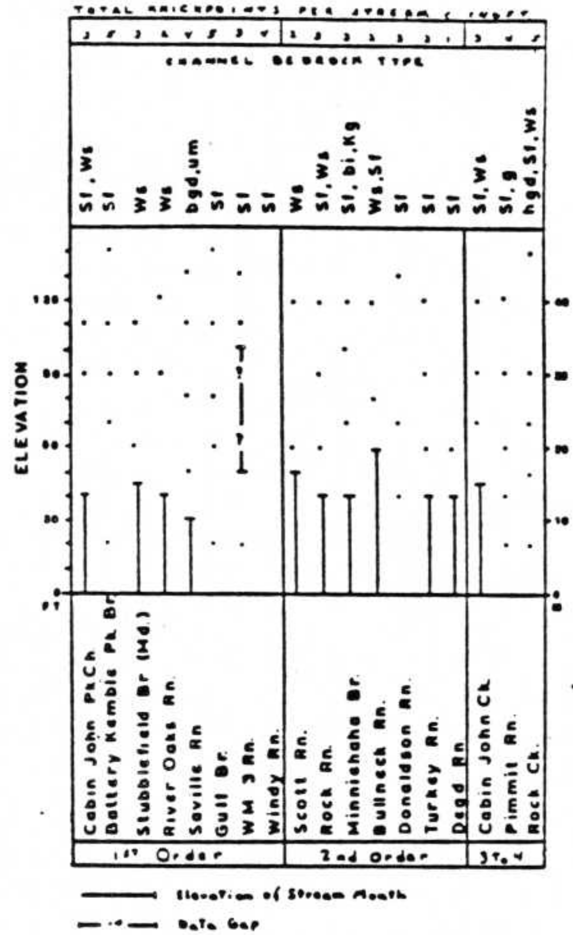


Figure 15. Falls Stretch tributary knickpoint frequency (Tormey, 1980, 1988).

rocks indicates range in yield within each rock type is greater than the difference between average yields of each rock type, Johnston, (1964);

4. Of the more than 65 knickpoints on the tributaries, only five mark contact zones mapped between one crystalline rock type and another--most are unrelated to lithologic differences of formational magnitude;

5. Knickpoints on the trunk stream are mirrored in miniature on many of the tributaries in the Falls Stretch.

The Effects of Macrostructure and Joint-Lineation Control

While eustasy largely influenced vertical development of the Falls Stretch, macrostructure and joint-lineation control are dominant factors in horizontal development.

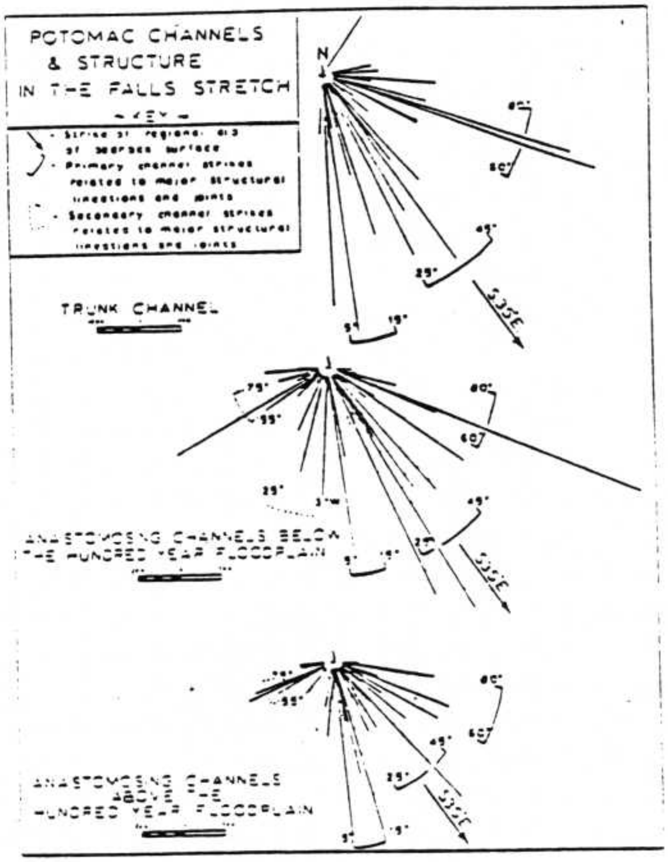
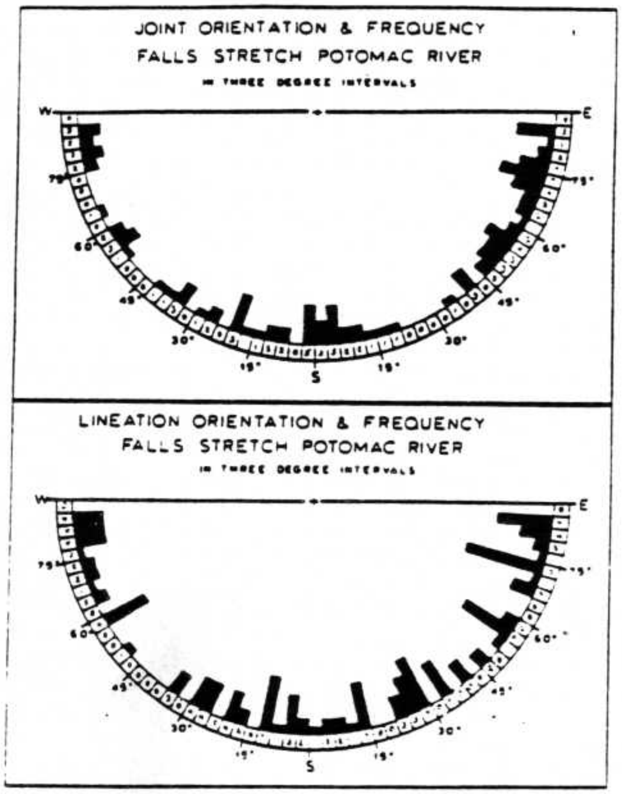


Figure 16. Joint and lineation orientation and frequency in the Falls Stretch (Tormey, 1980, 1986).

Flow of the Potomac is consequent to the Piedmont surface which dips southeast (near S. 35° E.) at a rate greater than 100 feet per mile. In Figure 16, channel directions illustrated earlier are shown together to facilitate comparison. Regional slope of the crystalline surface partially explains both the cluster of trunk channels, and the cluster of channel segments below the hundred-year floodplain near S. 35° E. It lends weight to the two clusters near S. 10° E. and S. 40° E. on the diagram of channel segments above the hundred-year floodplain. Apparently regional slope has greatest effect on channels between S. 25° E. and S. 40° E. Few joints have been mapped within these bounds; however lineations occur with greater frequency between 20° and 30°. Channel orientations reflect the weighting effects of this structural control by occurring more readily between 20° and 30° than between 30° and 40°. Greater appreciation of the river's response to bedrock slope may be explained upon examination of the regional joint-lineation network. Strong channel development striking between S. 60° E. and S. 80° E. results from well developed joints and lineations with similar strike.



Figures 17-A & B. Joint directions and lineation orientations in the Falls Stretch (Tormey, 1980).

Joint directions mapped in the field and supplemented by those from available geologic maps are plotted in Figure 17-A. Structural lineations apparent on air photographs are plotted in Figure 17-B. Although both joint sets and lineations show a wide range in strike orientation, they are most numerous in the southeast quadrant. The combined effects of more numerous, closer planes of weakness striking down the dip of regional slope accounts for the strong tendency for channel development in this quadrant.

Some degree of "scatter" in channel development in the anastamosing channels rose diagram is attributed to two factors: local depth of alluvium, and local dominance of particular joint sets. In the latter case, the two clusters near S. 10^{o} E. and S. 40^{o} E. serve as an example. Both strike clusters occur on Bear Island. Local dominance of these sets and absence of intervening sets would influence channel development down the bedrock slope to the local lineations.

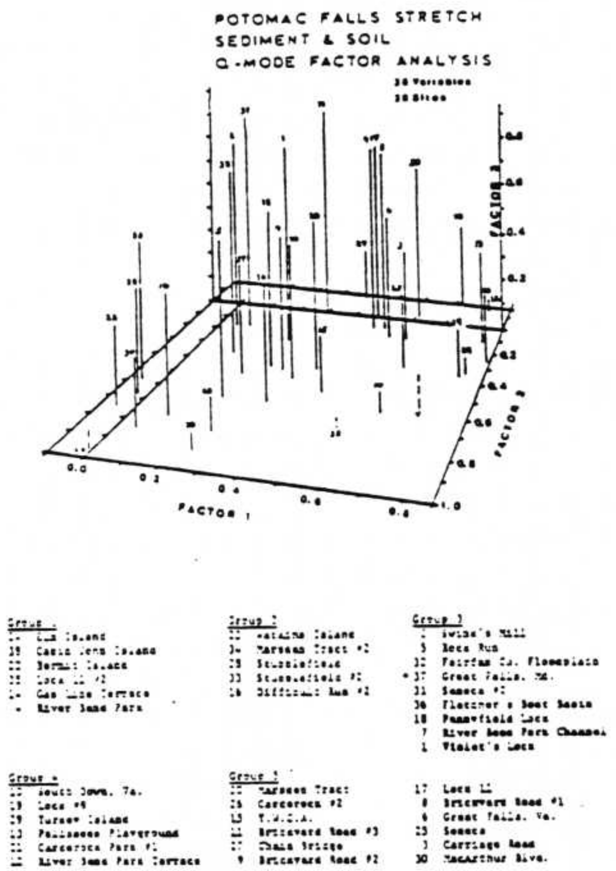


Figure 18. Triaxial diagram of factor loadings for the first three factors of sediment and soil Q-mode factor analysis. Five groups are identified.

THE EFFECTS OF SEDIMENTATION AND PEDOGENESIS

The effects of sedimentation and pedogenesis in the Falls Stretch were indicated via R- and Q-mode factor analysis of various properties resulting from a complex association of natural causes (Tormey, 1980, 1982). R-mode analysis highlighted many variable associations not immediately obvious. Q-mode analysis permitted distinction of five groups of soils and resolved some areas of confusion from earlier, less detailed mapping efforts (Fig. 18). The soil groups resulting from this analysis were delineated on the basis of two types of variables: the sedimentary variables related to particle size, shape and provenance and certain soil development variables, characterizing soil color, mottling and clay illuviation. Figures 19 and 20 portray some of the characteristics of each of the groups. Listed below is an abridged caricature of each group.

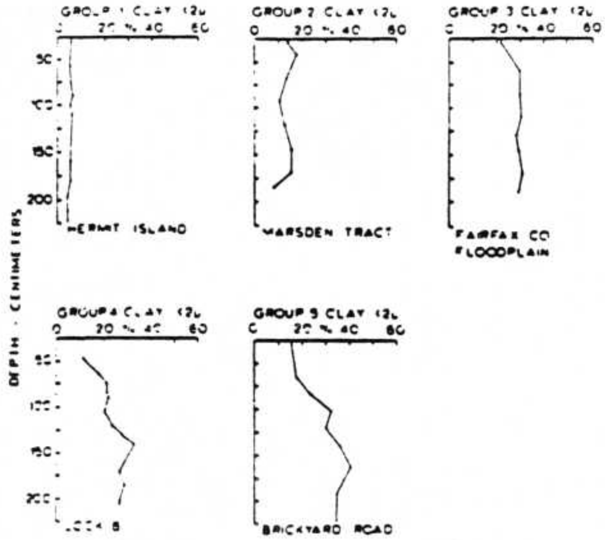


Figure 19. Typical percent clay distribution in soil group.

Group 1 soils are sandy, well drained, poorly developed, floodplain soils found where trunk channel gradients are steeper, and overbank stream velocities higher, with deposition occurring on lee sides of islands and higher well drained areas of the modern floodplain. Deposits rarely contain granule size (-2) gravel, generally less than 1%. They typically show no clay illuviation.

Group 2 soils are modern floodplain soils comprised of higher accumulations of silt than Group 1 soils. They occur at intermediate levels on the floodplain below the higher, better drained soils of Group 1, and along wider reaches of the trunk channel. Deposits rarely contain granule (-2) gravel. Although higher occurrence of clay than Group 1 may be observed in the profiles, this is most likely the result of in situ cyclic deposition rather than illuviation.

Group 3 soils are poorly drained modern floodplain soils high in silt and clay content occurring in anastamosed channels and backwater sloughs. In anastamosed channels, sediments typically coarsen with increasing depth to granule sizes (-2 to -3) and comprise up to 10% of the total mass. Deposits sampled in backwater sloughs typically terminate at the -1 sand-gravel boundary.

Group 4 soils are all found on terraces above the modern floodplain. Soils from four sites occur along the trunk channel below Great Falls and between the 100-120 foot contour. Two other sites occur upstream from Great Falls. The sites all contain granule size (-2) gravel, exceeding 2% concentration only as a result of surficial colluvium or the presence of a stone line. The group shows a moderate to strong clay illuviation.

Group 5 soils are formed on terraces above the modern floodplain primarily downstream from Great Falls. These soils differ from terrace soils in Group 4 by their generally higher silt and clay content, solum thickness, and limited

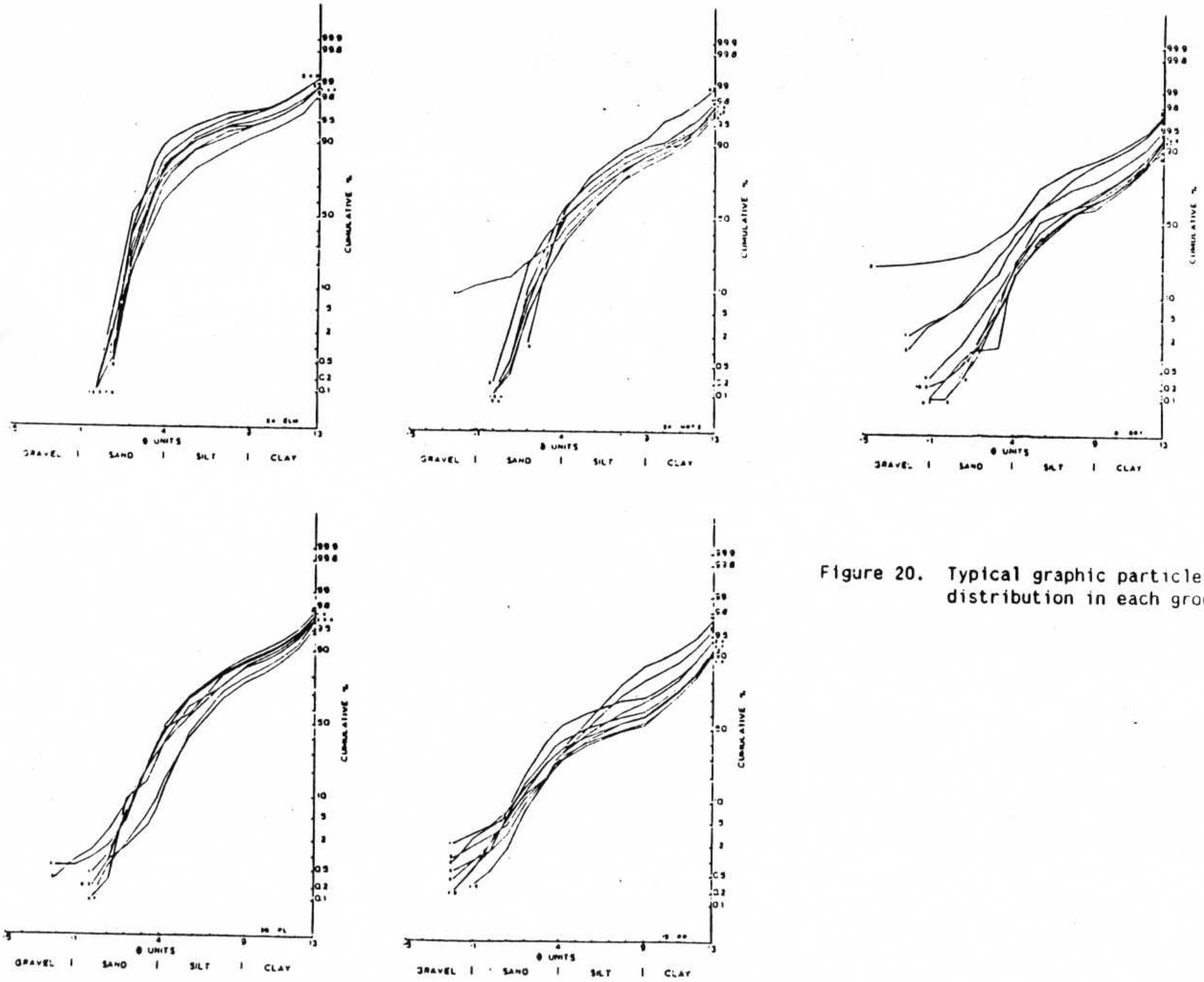


Figure 20. Typical graphic particle size distribution in each group.

lithologic variety in the greater than granule size gravel (-2). Although some terraces at elevations similar to Group 4 are included, the group also encompasses terraces at generally higher elevations downstream. Deposits commonly contain granule or larger size gravel as stone lines, basal gravels or surficial colluvium. Clay illuviation is indicated by moderate to strong development of clay bulges, with greatest development on highest and oldest terraces.

SUMMARY

This guide presents an overview of the geomorphology of the Falls Stretch of the Potomac River, both to illuminate details of local morphology and to illustrate their relation in the general scheme of Atlantic coast geomorphology. It presents the Potomac as an empirical model in the interpretation of other Fall Zone rivers along the southern Atlantic coast, and identifies sediment and soil parameters useful in delineating floodplain and terrace deposits of a modern river, subject to large interval floods. It further illustrates yet another dimension of the utility of this river as an outdoor learning laboratory.

EDUCATIONAL ACTIVITIES

Opportunities to both clarify major issues of Appalachian tectonism and Pleistocene eustasy and provide students (at a variety of levels), with broad-based field interpretive skills abound in the Falls Stretch of the Potomac River, and other major Fall Zone rivers, where bedrock exposures are exceptional and river terrace deposits link the coastal plain with the continental interior. Whether planning a brief study, or a series of protracted long-term investigations, the Falls Stretch of the Potomac River offers both an extensive array of field activities over numerous easy access points and a rugged natural setting in the publicly managed park lands. A geological smorgasbord of suggested topics for further study is included in a recently published article (Tormey, 1989).

Authorization for sampling on public lands should be obtained in advance from: Chief Ranger, C. & O. Canal National Historical Park, National Park Service; Superintendent, George Washington Parkway, National Park Service; and Park Operations Superintendent, Northern Virginia Regional Park Service. The list of individuals from these and other governmental agencies to whom we owe a continuing debt of thanks is indeed lengthy. To all, we extend our sincere appreciation for their assistance. Without such cooperation, much of this work would not have been possible.

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In addition to the geologic and soils maps of the Falls Stretch of the Potomac (included as pocket material for field trip participants), a set of five maps detailing the geomorphology of the Falls Stretch is available (at cost) upon request from the author.

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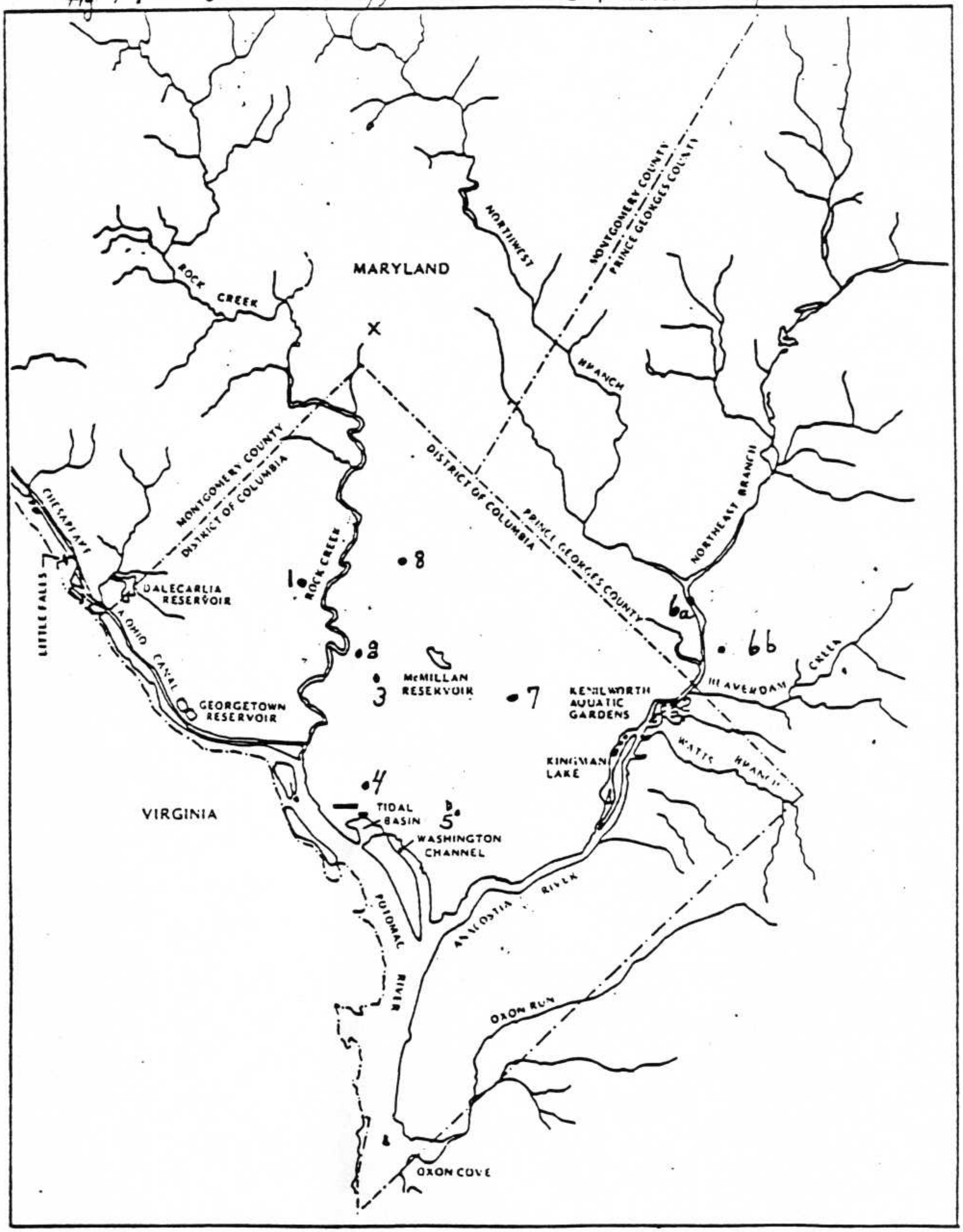
Fig 1: D.C. Geology Field Sites: Urban Exploration



URBAN GEOLOGY OF THE DISTRICT OF COLUMBIA

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University of the District of Columbia

The District of Columbia has a rich geologic heritage and many ideal stops for earth science teaching or geological research. This half day circula excursion exposes some of the classic textbook urban geology. Since conducting a similar NAGT trip twelve years ago (O'Connor,1977), both the city growth and geologic investigations have changed our earlier ideas and interpretations. As a Fall Line city, Washington lies on the boundary between the geomorphic regions of the Piedmont Pleateau and Atlantic Coastal Plain. The metamorphic and structural history of the Paleozoic is encountered in the northwest of the city. The dynamic fluvial-deltaicx-estuarine systems from the Cretaceous to th Ice Age have left sedimentary deposits exposed in cliffs and under terraces fo the rest of the District. Superimposed on these two divergent geologies is the evolving DC urbiscape. After the establishment of the District of Columbia (1790s) as the Nation's Capital, Pierre L'Enfant planned out the city of Washington. This year is the centennial of the National Zoo. Next Year is the centennial of Rock Creek Park, one of the first national parks and planned city parks. The bicenntennial of DC is coming up. How has DC used its geology? What Earth Science secrets are still observable?
How has geology helped or hindered the growth and development of this city of magnificent intentions?

STOP 1: NEWARK STREET QUARRY (off Conn. Ave. NW.--private property)

The Newark Street Quarry was reclaimed for a series of stores in Cleveland Park during the 1930s. The rock, known locally as Rock Creek Granite or the Kensington Granite Gneiss (Fig.2), is a small pluton that follows the axis of the Baltimore-Washington anticlinorium. Quarry operations provided foundation and porch stone for the dwellings in the neighborhood.
The neighborhood is named for President Grover Cleveland who had his summer retreat here. The estate of Gardiner Greene Hubbard, founded of National Geographic, still exists in the neighborhood.
The rock is foliated with biotite and feldspar layers. This rock weathers easily with the feldspars turning to clay and the biotite leaching iron. The quarry wall exists behind the theatre and store complex.

STOP 2: ADAMS MILL ROAD THRUST FAULT & ZOO GATES

Preserved at the headquarters gate for the National Zoo is a Coastal Plair thrust fault. The Piedmont schist has been pushed up and through the Coastal Plain gravels. The exposure to the elements has turned the schist to saprolite but tree roots follow the fault plane into the ground. The throw is estimated to be between 45-60 feet (app.15m) to the northwest (Fig.3). Other fault activity recorded in the zoo grounds include the auto tunnel; lion house, Metr excavation, and the quarry on the west bank. N.H. Darton photographed the faults in the area during the street improvement project and was instrumental in the preservation of this outrcrop for future generations.
The original gates of the zoo are composed of local stone. These rocks were chosen and set in place to start a long term research study on how local rocks behave in the humid climate of Washington. While observational studies are continuously done, no formal research has been accomplished to date.

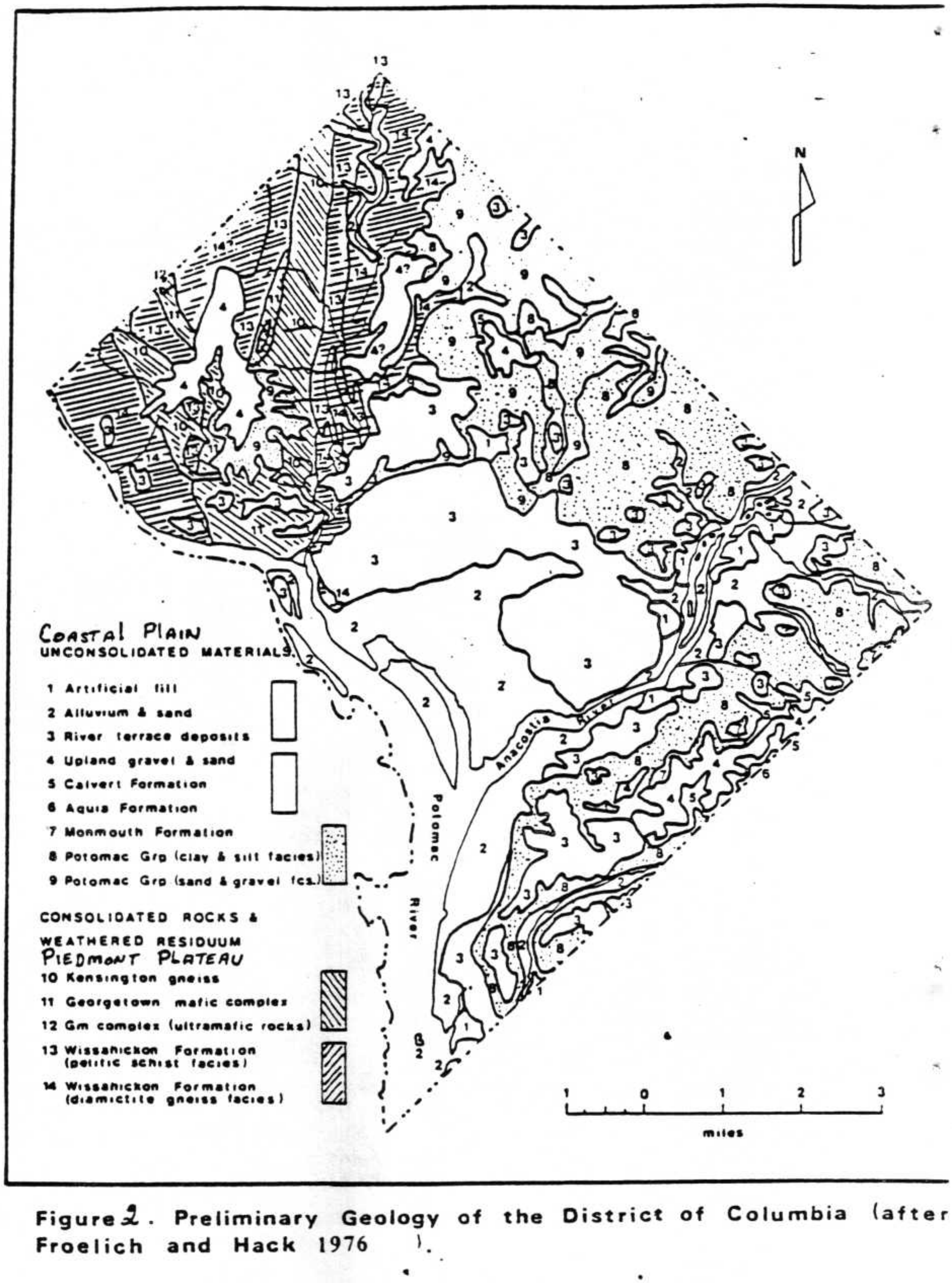


Figure 2. Preliminary Geology of the District of Columbia (after Froelich and Hack 1976).

TABLE 1.--RELATIONSHIP BETWEEN POSITION, PARENT MATERIAL, AND DRAINAGE OF SOIL SERIES AND OTHER TAXA

Parent Material	Excessively drained	Somewhat excessively drained	Well drained	Moderately well drained	Somewhat poorly drained	Poorly drained	Very poorly drained
			UPLAND SOILS FORMED IN PIEDMONT RESIDUUM				
Micaceous schist and impure quartzite.		Manor	Manor				
Acid schist and impure quartzite.			Glenelg	Glenelg Variant			
Gneiss.	Ashe	Ashe					
Gneiss-skeletal.	Brandywine	Brandywine					
Semibasic or mixed basic and acidic rocks.			Neshaminy				
			UPLAND SOILS FORMED IN COASTAL PLAIN SEDIMENT				
Clay and silty clay.			Christiana	Keyport			
Sand over clay, silty clay, or sandy clay.		Muirkirk Variant	Sunnyside				
Silt over sandy sediment.			Matapeake				
Silt over compacted silt, sand, and gravel.			Chillum	Beltsville			
Sand, silt, and clay.			Sassafras	Woodstown		Fallsington	
Sand, silt, and clay over compacted sand.				Bourne			
Sand and loamy sand.		Galestown					
Loamy sand and sandy loam.		Rumford					
Gravelly silt and sand.	Joppa	Joppa	Joppa				
Old gravelly sediment.		Croom					
			FLOOD-PLAIN SOILS FORMED IN RECENT ALLUVIUM AND RIVER DREDGINGS				
Alluvium from Piedmont material.				Codorus	Codorus	Fluvaquents and Fluvents.	Fluvaquents and Fluvents.
Alluvium from Coastal Plain sediment.			Udifluvents	Iuka		Bibb	
Sandy alluvium and river dredgings.			Udifluvents, sandy.	Udifluvents, sandy.		Bibb	
Silty alluvium and river dredgings.				Lindside		Melvin	Dunning

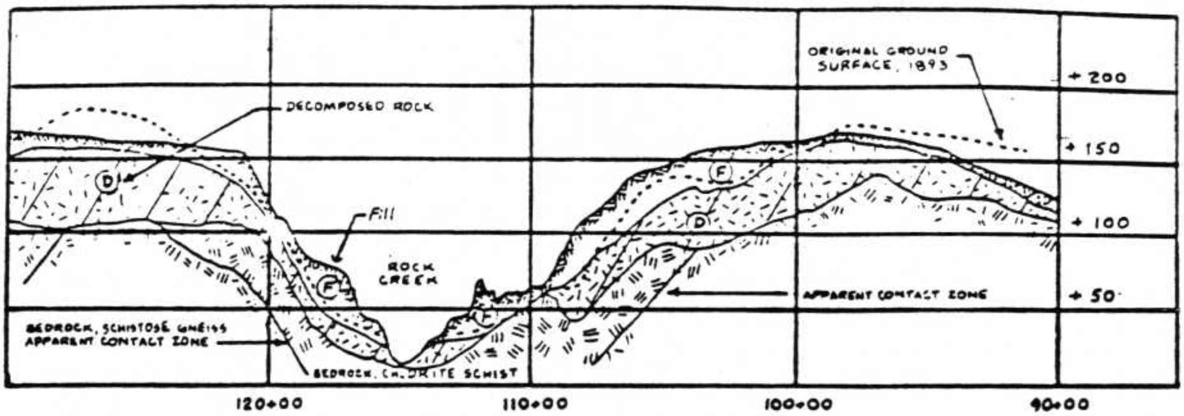
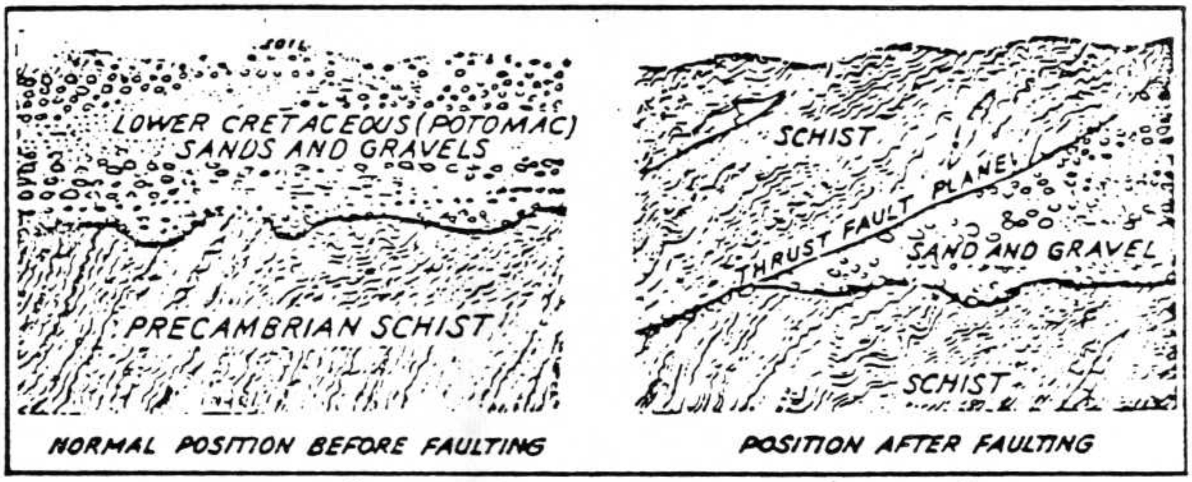


FIGURE 3c GEOLOGIC CROSS-SECTION OF ROCK CREEK METRO CROSSING SITE



NORMAL POSITION BEFORE FAULTING — *POSITION AFTER FAULTING*

FIGURE 3a **FIGURE 3b**

COPY OF THE EXHIBITION LABEL EXPLAINING STRUCTURE OF THE AREA ALONG ADAMS MILL ROAD NEAR ZOO GATE. BEFORE AND AFTER FAULTING.

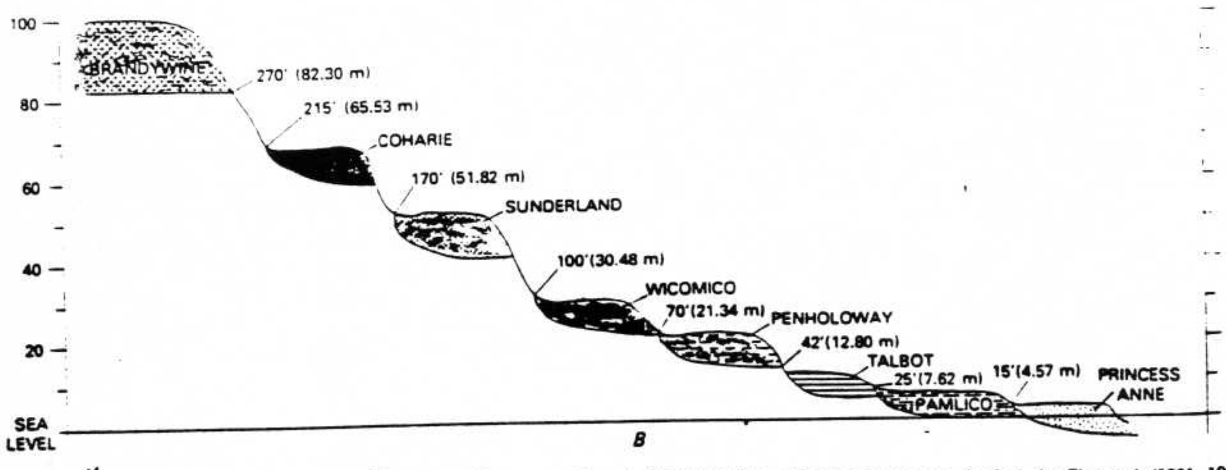


FIGURE 4—The marine terrace concept. Diagrammatic cross sections to illustrate the marine terraces recognized: *A*, by Shattuck (1901, 1902, 1906); *B*, by Cooke (1930, 1958).

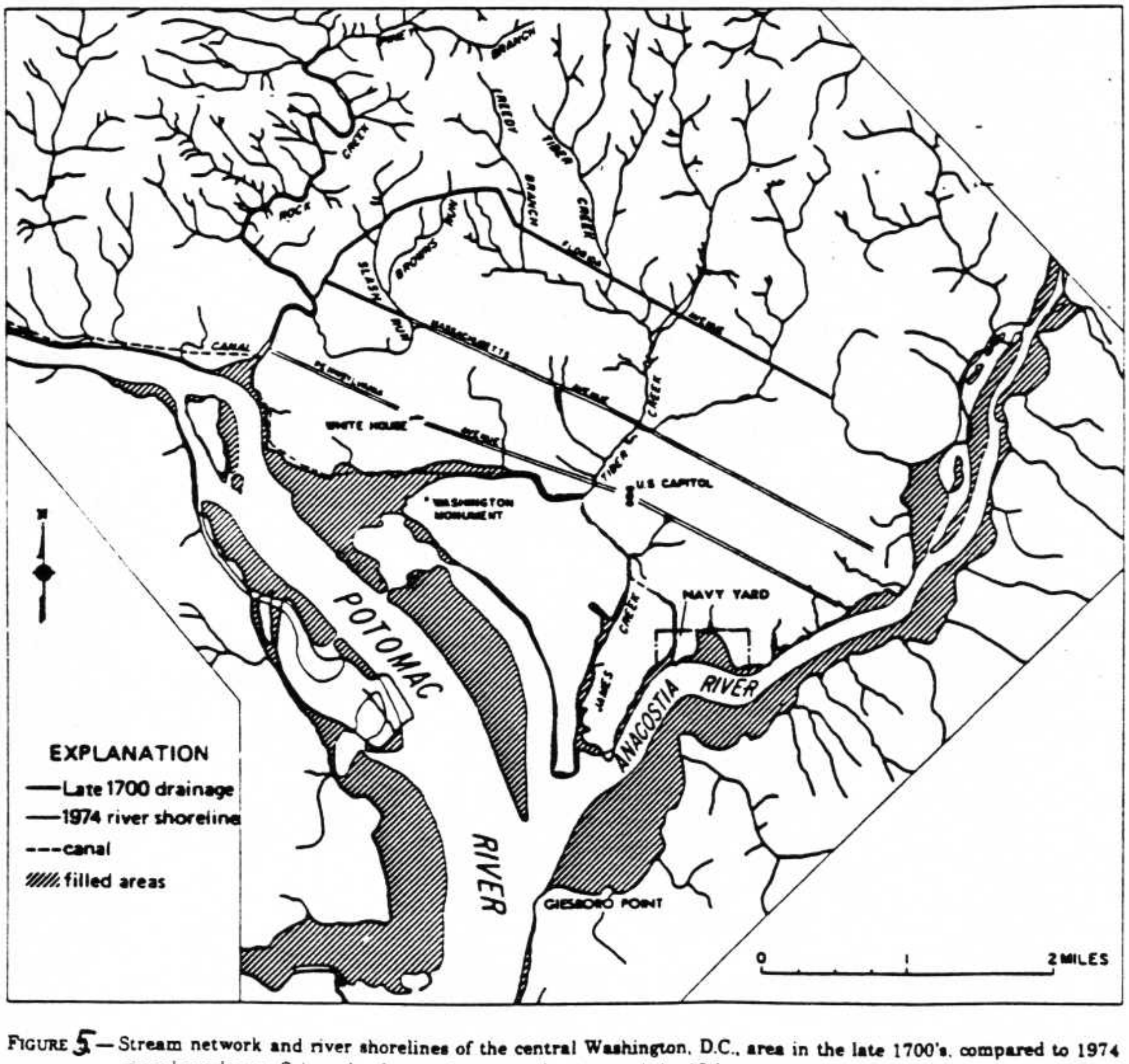


FIGURE 5—Stream network and river shorelines of the central Washington, D.C., area in the late 1700's, compared to 1974 river boundaries. Selected reference streets and points and the 19th-century canals are also shown.

STOP 3: MERIDIAN HILL PARK AND THE COASTAL PLAIN TERRACES (16th Street N

The large neighborhoods of the District of Columbia are spread out on the fluvial-estuarine terraces of the Atlantic Coastal Plain (Fig.4). Meri Hill is one populous area locked on the geological foundation and overlooking t original Washington City of Pierre L'Enfant. The original city ended at th base of the escarpment called Florida Ave or Boundary Street. Recent evide indicates that this curved street is more likely a meander curve than a shoreline or beach of previous beliefs. The Park is designed as a series o terraces with waterfalls. The place name comes from Thomas Jefferson's att to have the prime meridian run along 16th Street from the zero milestone o Ellipse. The view of the White House and the offset Washington Monument highlights the mathematical plan of L'Enfant versus the foundation geology monument was moved because of the engineering conditions on the Potomac mu flats.

STOP 4: SIDEWALK SECRETS at 15th Street and Constitution Avenue NW:

The role of federal and private building stones is easily accessed at this street corner. The gateposts and gatehouse of the Capitol were placed here during renovation of the Capitol grounds by Frederic Law Olmst after the Civil War. The gateposts have suffered from air pollution and th elements. These posts are the Virginia Freestone or Aquia sandstone of the Potomac Group (Cretaceous age) (note: this is not the glauconitic Aquia Formation of Tertiary Eocene age). The visible sedimentary features in the gatehouse are worth investigating:Cross-beds, graded beds and floods marks The Potomac floods were quite common on Pennsylvania Avenue before the lev was placed on the reflecting pool area. The March 1936 flood is the highes recorded on the river so far. Constitution Ave or old B Street is the sewe Tiber Creek. This DC stream flowed from springs at the Soldiers Home to empty into the Potomac at 17th Street and Constitution Avenue (Fig.5). Thi stream later was transformed into the flush system for the Washington City Canal which was the extension of the C & O Canal and linked the Navy Yard and Anacostia to Georgetown. The canal was a tidal bypass and allowed marble t shipped to the base of the Capitol for construction.

The Washington Monument has Maryland and Massachusetts marbles, find the break in the stone where the financial story sets in?

The Federal Triangle is composed of the Indiana limestone (Mississippian a and has numerous crinoids and bryozoans as fossil deltaic hash.

STOP 5: The CAPITOL

Symbols are the key to many ways of life and the stone monument for our democratic power is no exception. Few view the seat of government as a geologic museum but there are many geologic chapters in this building.

The granite stairs show the ware and tear of shoe abrasion. The stairs on north still have their wire marks while the center stairs do not. The oute marble is a hallmark to Appalachain marbles from Gerogia and Maryland but the original main interior is composed of Virginia and Maryland stone. original walls are the Virginia Freestone with its beautiful crossbeds. Statuary Hall has the columns of Potomac Marble or Leesburg conglomerate. Mesozoic fanglomerate has gained famed because of its use here after being brought down the Potomac.

Times and Heights of High and Low Waters

APRIL

Day	Time (h m)	Height (ft)	Height (m)
1 Sa	0303	2.7	0.8
	0954	0.6	0.2
	1520	3.0	0.9
	2249	0.5	0.2
2 Su	0407	2.9	0.9
	1103	0.4	0.1
	1626	3.1	0.9
	2341	0.4	0.1
3 M	0503	3.2	1.0
	1207	0.2	0.1
	1727	3.2	1.0
4 Tu	0033	0.2	0.1
	0553	3.4	1.0
	1305	0.0	0.0
	1822	3.3	1.0
5 W	0122	0.1	0.0
	0642	3.6	1.1
	1400	-0.1	0.0
	1914	3.3	1.0
6 Th	0210	-0.1	0.0
	0731	3.8	1.2
	1453	-0.2	-0.1
	2006	3.3	1.0
7 F	0257	-0.1	0.0
	0819	3.8	1.2
	1545	-0.2	-0.1
	2056	3.3	1.0
8 Sa	0345	-0.1	0.0
	0906	3.7	1.1
	1638	-0.2	-0.1
	2147	3.1	0.9
9 Su	0435	-0.1	0.0
	0956	3.6	1.1
	1731	-0.1	0.0
	2241	3.0	0.9
10 M	0526	0.1	0.0
	1048	3.4	1.0
	1826	0.0	0.0
	2338	2.8	0.9
11 Tu	0621	0.2	0.1
	1142	3.1	0.9
	1922	0.1	0.0
12 W	0043	2.6	0.8
	0720	0.3	0.1
	1247	2.9	0.9
	2021	0.2	0.1
13 Th	0149	2.5	0.8
	0822	0.4	0.1
	1358	2.7	0.8
	2117	0.3	0.1
14 F	0254	2.6	0.8
	0925	0.5	0.2
	1508	2.6	0.8
	2213	0.3	0.1
15 Sa	0354	2.6	0.8
	1027	0.5	0.2
	1611	2.6	0.8
	2304	0.3	0.1

Day	Time (h m)	Height (ft)	Height (m)
16 Su	0448	2.7	0.8
	1125	0.4	0.1
	1703	2.7	0.8
	2349	0.3	0.1
17 M	0535	2.9	0.9
	1218	0.4	0.1
	1754	2.7	0.8
18 Tu	0031	0.4	0.1
	0617	3.0	0.9
	1305	0.4	0.1
	1838	2.8	0.9
19 W	0110	0.4	0.1
	0652	3.1	0.9
	1350	0.3	0.1
	1917	2.9	0.9
20 Th	0147	0.4	0.1
	0726	3.2	1.0
	1431	0.4	0.1
	1956	2.9	0.9
21 F	0222	0.5	0.2
	0753	3.3	1.0
	1513	0.4	0.1
	2029	2.9	0.9
22 Sa	0255	0.6	0.2
	0822	3.4	1.0
	1553	0.5	0.2
	2104	2.8	0.9
23 Su	0330	0.6	0.2 L
	0852	3.4	1.0 H
	1633	0.6	0.2 L
	2136	2.8	0.9 H
24 M	0409	0.7	0.2
	0927	3.4	1.0
	1714	0.6	0.2
	2211	2.8	0.9
25 Tu	0447	0.8	0.2
	1008	3.4	1.0
	1756	0.7	0.2
	2251	2.8	0.9
26 W	0532	0.8	0.2
	1051	3.4	1.0
	1842	0.7	0.2
	2339	2.8	0.9
27 Th	0624	0.8	0.2
	1142	3.3	1.0
	1928	0.7	0.2
28 F	0033	2.8	0.9
	0723	0.8	0.2
	1241	3.2	1.0
	2021	0.7	0.2
29 Sa	0132	2.9	0.9
	0830	0.8	0.2
	1346	3.1	0.9
	2115	0.6	0.2
30 Su	0234	3.0	0.9
	0939	0.7	0.2
	1456	3.1	0.9
	2210	0.5	0.2

MAY

Day	Time (h m)	Height (ft)	Height (m)
1 M	0337	3.2	1.0
	1047	0.5	0.2
	1603	3.1	0.9
	2305	0.4	0.1
2 Tu	0434	3.4	1.0
	1149	0.3	0.1
	1703	3.1	0.9
	2359	0.3	0.1
3 W	0527	3.6	1.1
	1248	0.1	0.0
	1801	3.2	1.0
4 Th	0050	0.2	0.1
	0617	3.8	1.2
	1344	0.0	0.0
	1855	3.2	1.0
5 F	0142	0.1	0.0
	0707	3.8	1.2
	1439	-0.1	0.0
	1946	3.2	1.0
6 Sa	0232	0.1	0.0
	0756	3.8	1.2
	1531	-0.1	0.0
	2037	3.1	0.9
7 Su	0323	0.1	0.0
	0845	3.7	1.1
	1622	-0.1	0.0
	2131	3.0	0.9
8 M	0414	0.1	0.0
	0936	3.6	1.1
	1715	0.0	0.0
	2223	2.9	0.9
9 Tu	0507	0.2	0.1
	1027	3.4	1.0
	1804	0.1	0.0
	2321	2.8	0.9
10 W	0600	0.3	0.1
	1123	3.1	0.9
	1856	0.2	0.1
11 Th	0021	2.7	0.8
	0656	0.4	0.1
	1223	2.9	0.9
	1946	0.2	0.1
12 F	0124	2.7	0.8
	0755	0.5	0.2
	1327	2.8	0.9
	2036	0.3	0.1
13 Sa	0223	2.7	0.8
	0854	0.6	0.2
	1433	2.7	0.8
	2124	0.4	0.1
14 Su	0320	2.8	0.9
	0952	0.6	0.2
	1533	2.7	0.8
	2213	0.4	0.1
15 M	0410	2.9	0.9
	1050	0.6	0.2
	1629	2.7	0.8
	2257	0.4	0.1

Day	Time (h m)	Height (ft)	Height (m)
16 Tu	0456	3.0	0.9
	1143	0.5	0.2
	1718	2.7	0.8
	2340	0.5	0.2
17 W	0538	3.1	0.9
	1234	0.5	0.2
	1804	2.8	0.9
18 Th	0022	0.5	0.2
	0615	3.2	1.0
	1321	0.5	0.2
	1846	2.8	0.9
19 F	0105	0.6	0.2
	0648	3.3	1.0
	1407	0.5	0.2
	1926	2.8	0.9
20 Sa	0144	0.6	0.2
	0718	3.4	1.0
	1450	0.5	0.2
	2003	2.8	0.9
21 Su	0225	0.7	0.2
	0750	3.5	1.1
	1532	0.5	0.2
	2039	2.8	0.9
22 M	0307	0.7	0.2
	0825	3.5	1.1
	1614	0.6	0.2
	2111	2.8	0.9
23 Tu	0349	0.8	0.2
	0904	3.5	1.1
	1656	0.6	0.2
	2148	2.9	0.9
24 W	0435	0.8	0.2
	0948	3.5	1.1
	1736	0.6	0.2
	2232	2.9	0.9
25 Th	0522	0.8	0.2
	1034	3.4	1.0
	1821	0.6	0.2
	2320	2.9	0.9
26 F	0616	0.8	0.2
	1126	3.3	1.0
	1904	0.6	0.2
27 Sa	0011	3.0	0.9
	0715	0.7	0.2
	1224	3.2	1.0
	1951	0.5	0.2
28 Su	0109	3.1	0.9
	0818	0.7	0.2
	1328	3.1	0.9
	2042	0.5	0.2
29 M	0209	3.2	1.0
	0923	0.6	0.2
	1435	3.0	0.9
	2134	0.4	0.1
30 Tu	0308	3.3	1.0
	1029	0.5	0.2
	1540	2.9	0.9
	2231	0.3	0.1
31 W	0407	3.4	1.0
	1133	0.3	0.1
	1642	2.9	0.9
	2328	0.2	0.1

JUNE

Day	Time (h m)	Height (ft)	Height (m)
1 Th	0504	3.6	1.1
	1234	0.2	0.1
	1741	2.9	0.9
2 F	0024	0.2	0.1
	0556	3.6	1.1
	1331	0.1	0.0
	1838	2.9	0.9
3 Sa	0119	0.2	0.1
	0649	3.6	1.1
	1426	0.0	0.0
	1930	2.9	0.9
4 Su	0213	0.2	0.1
	0739	3.6	1.1
	1516	0.0	0.0
	2022	2.9	0.9
5 M	0307	0.2	0.1
	0828	3.5	1.1
	1607	0.0	0.0
	2115	2.9	0.9
6 Tu	0359	0.2	0.1
	0918	3.4	1.0
	1654	0.0	0.0
	2208	2.8	0.9
7 W	0448	0.3	0.1
	1007	3.2	1.0
	1740	0.1	0.0
	2259	2.8	0.9
8 Th	0539	0.4	0.1
	1058	3.1	0.9
	1824	0.1	0.0
	2352	2.8	0.9
9 F	0631	0.5	0.2
	1154	2.9	0.9
	1906	0.2	0.1
10 Sa	0048	2.8	0.9
	0722	0.5	0.2
	1253	2.8	0.9
	1949	0.3	0.1
11 Su	0140	2.8	0.9
	0818	0.6	0.2
	1349	2.7	0.8
	2031	0.3	0.1
12 M	0234	2.9	0.9
	0913	0.6	0.2
	1449	2.6	0.8
	2115	0.4	0.1
13 Tu	0323	2.9	0.9
	1011	0.6	0.2
	1547	2.6	0.8
	2159	0.5	0.2
14 W	0410	3.0	0.9
	1106	0.6	0.2
	1639	2.6	0.8
	2247	0.5	0.2
15 Th	0452	3.1	0.9
	1201	0.6	0.2
	1729	2.6	0.8
	2333	0.6	0.2

Day	Time (h m)	Height (ft)	Height (m)
16 F	0533	3.2	1.0
	1251	0.6	0.2
	1814	2.7	0.8
17 Sa	0022	0.6	0.2
	0610	3.3	1.0
	1339	0.5	0.2
	1856	2.7	0.8
18 Su	0111	0.7	0.2
	0646	3.4	1.0
	1425	0.5	0.2
	1935	2.7	0.8
19 M	0200	0.7	0.2
	0725	3.5	1.1
	1510	0.5	0.2
	2011	2.8	0.9
20 Tu	0247	0.7	0.2
	0804	3.5	1.1
	1551	0.5	0.2
	2051	2.9	0.9
21 W	0334	0.6	0.2
	0847	3.5	1.1
	1633	0.4	0.1
	2129	3.0	0.9
22 Th	0424	0.6	0.2
	0932	3.5	1.1
	1713	0.4	0.1
	2211	3.1	0.9
23 F	0513	0.6	0.2
	1020	3.4	1.0
	1754	0.4	0.1
	2259	3.1	0.9
24 Sa	0607	0.6	0.2
	1112	3.3	1.0
	1838	0.3	0.1
	2350	3.2	1.0
25 Su	0703	0.5	0.2
	1208	3.2	1.0
	1924	0.3	0.1
26 M	0044	3.2	1.0
	0804	0.5	0.2
	1309	3.0	0.9
	2013	0.3	0.1
27 Tu	0143	3.3	1.0
	0908	0.5	0.2
	1414	2.8	0.9
	2106	0.3	0.1
28 W	0244	3.3	1.0
	1014	0.4	0.1
	1520	2.7	0.8
	2205	0.2	0.1
29 Th	0345	3.3	1.0
	1121	0.3	0.1
	1626	2.7	0.8
	2306	0.2	0.1
30 F	0445	3.3	1.0
	1222	0.2	0.1
	1727	2.7	0.8

Time meridian 75° W. 0000 is midnight. 1200 is noon.
Heights are referred to mean lower low water which is the chart datum of soundings.

TABLE : 2 TIDE TABLES - Spring 89 - DC NOAA - NOS

TIDE GAGING RECORD ANALYSIS FOR WASHINGTON,D.C.

J.V.O'Connor ©

1.What are the times for high tide today?

2. What are the times for low tide today?

3. How do you translate afternoon times in regular time?

4. What is the height of the highest high tide for today?

5. What is the depth of the lowest low tide for today?

6. What is zero feet (0') called?

7. What does a minus sign for depth mean under the height data?

8. What then is the tidal range (highest minus lowest) for today?

9. Calculate the total time of the ebb tidal current(high time-low tim

10. Calculate the total time for the flood tidal current(low time to h

11. Does the tide water energy take longer to go out or come in?

12. Which day or days of this month had the highest high water?

13 Which day or days had the lowest low waters?

14. What is the maximum tidal range for this month (HH-LL)?

15. On the data sheet,code in the four phases of the moon for this mon

16. Which moon phases do the high high waters relate too?

17. Which moon phases do the low low waters relate too?

18. What time period today would the sewers open their tide gates to discharge their waste into the Potomac or Anacostia?

19.When would the safest time be for a fresh water flood crest to pass through D.C. today?

20.As a rule of thumb people use to calculate tidal changes by adding one hour for tomorrows tides-how accurate is this method for D.C. tides?

tidal records from NOAA-NOS

TABle 3:

ANACOSTIA FLOODS-WATER YEARS (80-84)

Water Years	NW Branch Bank full	(Hyattsville) 1700 cfs	NE Branch	(Riverdale) 2000 cfs
1984	3/29/84	1930*	12/13/83	3680
			12/22/83	2100
			3/29/84	4300*
			5/4/84	2310
			5/26/84	2840
1983	3/27/83	1930	3/27/83	3250
	4/15/83	2230*	4/10/83	3130
	6/06/83	1880	4/15/83	4110
	6/19/83	1990	6/07/83	4280
			6/19/83	6010*
			6/20/83	3280
			8/05/83	4920
1982	5/28/82	2470*	6/01/82	2010*
1981	6/14/81	2060*	8/31/81	4410*
	9/15/81	1740		
1980	10/01/79	3780*	10/01/79	4170*
	6/7/80	1850	10/10/79	2010
			3/13/80	2250
			7/09/80	2370
			7/22/80	2130
5 Years	NW= 10 floods		NE = 19 floods	

Water year Oct-Sept e.g. 1986 WY = Oct. 85 to Sept. 86

* - Annual peak

2.33 yrs = statistical flood. natural stream

Stop 6 Geologic Section, east end of Jackson Street, Bladensburg, Maryland

Table 4 - Geologic Section - Jackson St.

[1 meter = 3.28 feet 1 foot = .305 meters]

Thickness Feet	Thickness Meters	(Top of section 190 feet above sea level)
Top	Top	RARITAN FORMATION (Upper Cretaceous)
13		Sand, buff, fine, clean, locally clayey. Thin ironstone layers throughout.
		PATAPSCO FORMATION (Upper Cretaceous)
22		Clay, red, silty to sandy, interfingers with gray lignitic clay.
5		Ironstone layer; iron-cemented sand and silt.
7		Clay, red.
9		Clay, light-gray.
12		Clay, red; iron-cemented layer in middle, 1 foot thick.
45		Clay, black to dark gray, contains siderite and limonite nodules, lignite, and silicified wood; sandy layers scattered throughout. (Parking lot is 105 feet above sea level and about 10 feet below top of this clay unit.) Hole drilled near eastern extent of Jackson Street for lower part of section.
5		Sand, white, fine to medium-grained.
1		Ironstone layer, iron-cemented sand.
10		Sand, yellow, medium-grained.
40		Clay, variegated, predominatly red, with green and purple.
5		Sand, olive-green, fined-grained. (This sand unit might represent the Patuxent Formation.)
8		Clay, white.

Total thickness: 182 feet (55.3 meters)
Base: 8 feet (2.4 meters) above sea level.

(O'CONNOR, 1977)

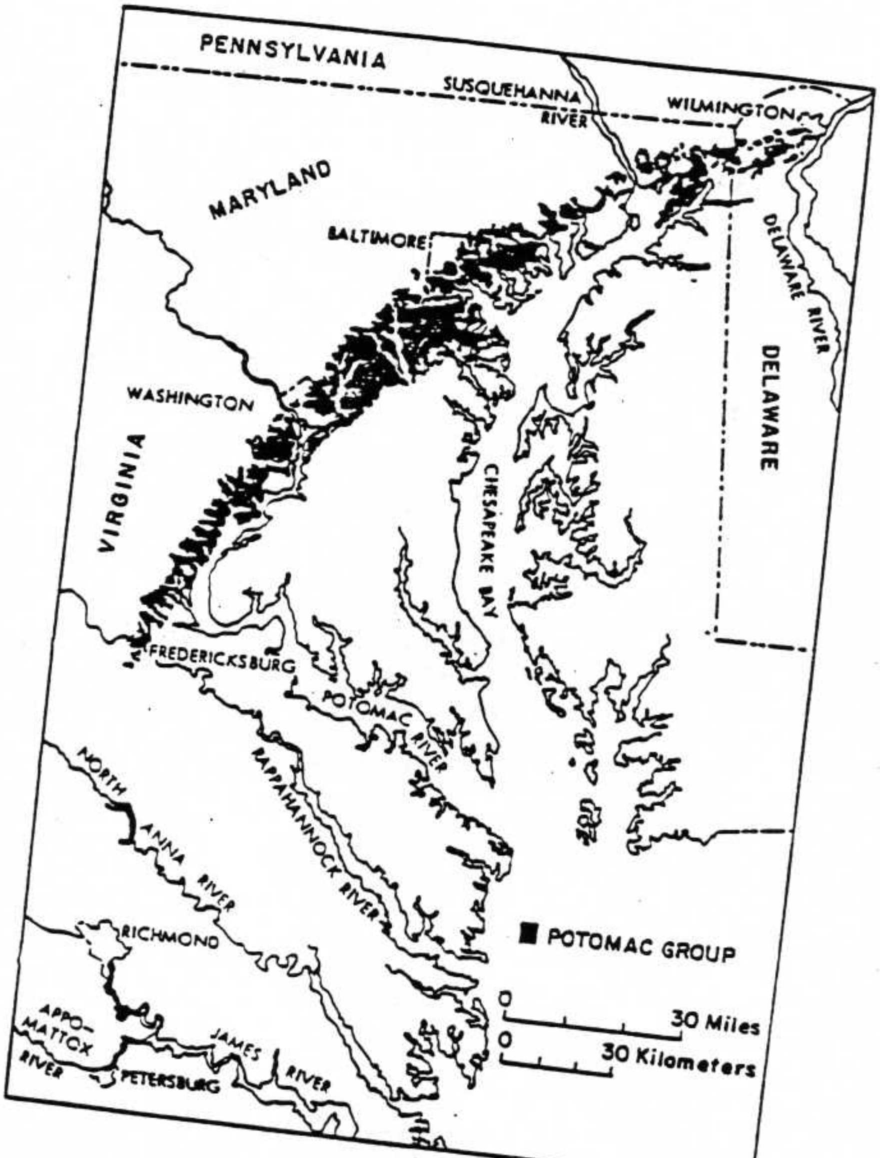


Fig. 6 . Outcrop map of the Lower Cretaceous Potomac Group in Virginia, Maryland, and Delaware. (Modified after Glaser, 1969 and reprinted with minor changes from Doyle and Hickey, 1976).

The statures are also important not only for our history but the solid mate
that each famous America is scultured from. Each state is allowed two
citizens from their realm to grace the interior. Follow the spiral staircas
to the rotunda museum. Study the Aquia columns. Observe the photoes that
document the building of the Capitol and changes to the neighborhood.
Carefully study the marble of the Suffraget statue. Bullet holes in the Aqu
from the British attack on the Capitol in August of 1814 are now covered.

STOP 6: PORT of BLADENSBURG

The summer of 1814 saw the British march overland to avoid the cannons of Fort Washington on the Potomac. The small tobacco port of Bladensburg became the site for the battle where the American forces were routed and the enemy sacked the new capital before moving to Baltimore and the fighting made famous in the Star Spangled Banner by Georgetown's Francis Sc Key. Bladensburg is still a tidewater town. The semi-diurnal pulse (Table 2 separates the Anacostia estuary from the fresh water confluence of the two tributaries for the Anacostia- the Northeast and Northwest branches (Table Because of their size and different drainage provinces these two branches c not have equal flows or flood patterns. The levee system built in the 1950s the US Army Corps of Engineers has saved property and lives worth more thar initial investment. Bladensburg was famous earlier for its natural health s and mineral waters loaded with sulphur and iron. The cliffs of Bladensburg (Table 4) are the deltaic and dinosaur red clays of the Potomac Group of Cretaceous age (Fig.6). While dinosaur bones are rare in these swamp and ma deposits, petrified wood and lignitized logs are common. The clay is subje swelling and causes slumps and slides especially where sand lenses occur. same clay is an excellent brick clay and the reason for so many brick comp in the area.

STOP 7: RHODE ISLAND AVENUE METRO STATION

On the shores of Tiber Creek stood a black military cemetary from the Civil War. Later the metropolitan division of the B & O railroad covered t stream and build a commuter railline to the suburbs. This line was recentl converted to a rapid rail system (METRO Red Line) for the area. New stati required new land uses. The cemetary was relocated and a parking lot cut o the hillside. The geology was the slumping red clay or Christiana soil. Th slump activity was fixed a few times with vegetation and drainage terraces will see this evidence of modern geology. The recent addition of the Post Office Central Sorting Facility has removed the back of the slide and stop the movement. Figure 7 is a contrast table to equate slope measurements for geologists, agronomists, and engineers.

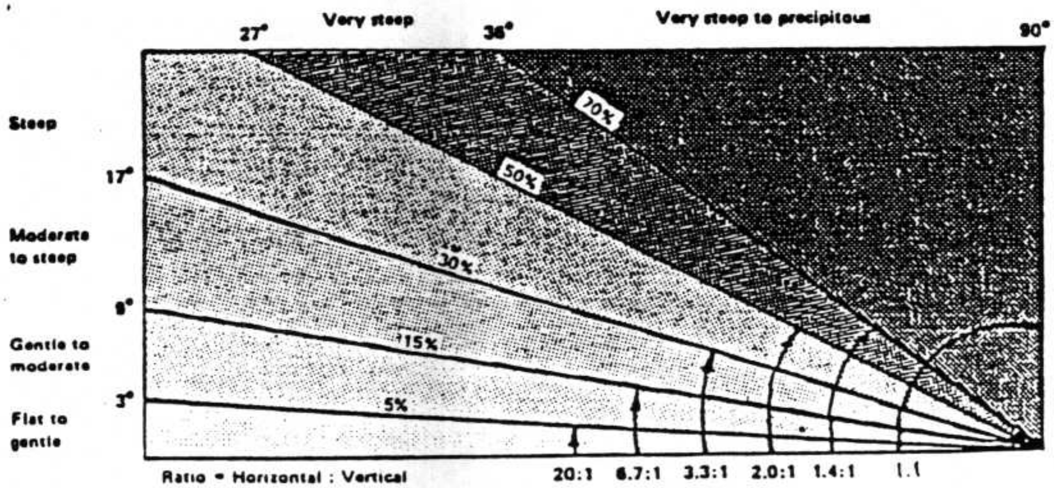


FIGURE 7: Categories of land slope expressed as percentages, degrees, and ratios.

STOP 8: ROCK CREEK CEMETARY

The laws that govern solid waste disposal have always regulated the public health issues associated with graveyards. Laws and cemetaries are changing. Graveyards with tombstones are becoming extinct. Cemetaries are ideal field sites to study weathering processes, learn your classification and identification of rocks and minerals and study local history.
This older cemetary in DC is noted for its famous residents such as Charles D. Walcott of Cambrian trilobite fame and the National Geographic family of Hubbards- Bells- and Grosnevors. Local famous families include the Blairs, Pierces, Adams, and Lords of Fairfax.
The use of the Rahn Scale for tombstone weathering is ideal for this site (Table 5). The source site for a 1925 USGS photo by W.T. Lee, currently appearing in many introductory texts, is found here (Fig. 8a,b). How has this special tablestone changed since 1925? The evolutionary break for this tombstone came in 1981.
Across the street is a military cemetary with its uniform marble stones. This site was part of the initial acid rain study on military cemetaries. The gates are carved from the Aquia sandstone and contrast nicely to the New York marbles of the Soldiers Home and Lincoln's summer retreat.

Table 5: THE RAHN CLASSES

CLASS 1 - UNWEATHERED

CLASS 2 - SLIGHTLY WEATHERED. FAINT ROUNDING OF CORNERS OF LETTERS

CLASS 3 - MODERATELY WEATHERED. ROUGH SURFACE; LETTERS LEGIBLE.

CLASS 4 - BADLY WEATHERED. LETTERS DIFFICULT TO READ.

CLASS 5 - VERY BADLY WEATHERED. LETTERS ALMOST INDISTINGUISHABLE.

CLASS 6 - EXTREMELY WEATHERED, NO LETTERS LEFT; SCALING SURFACE.

TOMBSTONE ANALYSIS NAME______________________________

DATE: TIME: WEATHER: LOCAL:

	NAME	BIRTH DATE	TIME SPAN	STONE TYPE	COMPASS HEADING	COMMENTS
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						
9.						
10.						

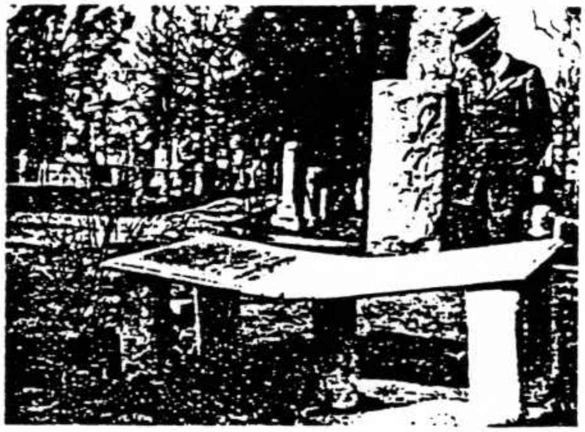
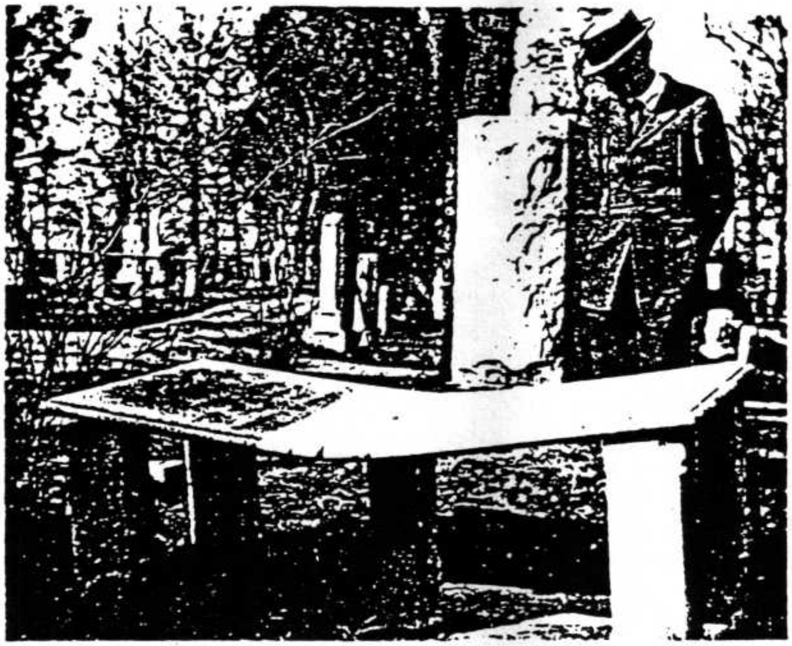


Figure 15.13 Marble slab that has sagged under its own weight
Photo by W. T. Lee, U.S. Geological Survey

a) from Plummer and McGeary: Physical Geology 3rd Ed (W

FIGURE 8: Rock Creek Cemetary Classic Tombstone in 1925.



8b: from G. Davis
Structural Geology (Wil

Figure 5.35 Marble bench bent downward by its own weight and that of the occasional occupant. The marble rheid is located in cemetery north of Soldiers' Home, Washington, D. C. (Photograph taken in 1925 by W. T. Lee. Courtesy of United States Geological Survey.)

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